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MILITARY AIRCREW SEATING: A HUMAN FACTORS ENGINEERING APPROACH

James D. Whiteley, CAPTAIN, USAF

DECEMBER 1989

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HARRY G. ARMSTRONG AEROSPACE MEDICAL RESEARCH LABORATORY
HUMAN SYSTEMS DIVISION
AIR FORCE SYSTEMS COMMAND
WRIGHT-PATTERSON AIR FORCE BASE, OHIO 45433-6573

NOTICES

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This report has been reviewed by the Office of Public Affairs (PA) and is releasable to the National Technical Information Service (NTIS). At NTIS, it will be available to the general public, including foreign nations.

The voluntary informed consent of the subjects used in this research was obtained as required by Air Force Regulation 169-3.

This technical report has been reviewed and is approved for publication.

FOR THE COMMANDER

CHARLES BATES, JR.
Director, Human Engineering Division
Armstrong Aerospace Medical Research Laboratory

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The application of human factors engineering to the realm of aerospace design is not a new or unique concept, however its direct application to aircrew seating to help solve pilot performance has largely been overlooked. This report presents aircrew seat design considerations, human response to whole body vibration, new seat design concepts, and several methods of evaluating and contrasting aircrew seats.

During this effort, two aircrew seats were developed. These primarily consisted of new seat pan and backrest structures. Two distinct experiments were performed. The first study was a controlled study using 15 male subjects which approximated the USAF pilot population. Data was collected to determine pressure distribution on the various seat pans in a static environment. The new seat pans were statistically different (lower maximum pressure) than the current seat pan. The current seat pan averaged almost double new seat pressure readings.

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The second experiment was a comfort/performance experiment in which 12 active duty Air Force males participated in a series of dynamic vibration exposure tests which simulated the actual flying environment. Performance tasks, subjective survey, and spinal creep measurements were accomplished. During the series of 90-minute vibration exposures, subjects did not statistically differ in their performance, however trends suggest that a longer duration could yield significant differences. The analysis of the body part discomfort form, general comfort rating, and aircrew seat feature checklist indicated that the current aircrew seat was rated as causing more pain and discomfort than the new seat. Overall, both new seats out-performed the current aircrew seat.

PREFACE

This document was produced as a Doctor of Philosophy Degree dissertation for the College of Engineering at Texas A&M University as part of an Air Force Institute of Technology program. The dissertation advisor for this effort was Dr Jerry Congleton of the Department of Industrial Engineering. My participation in this program was sponsored by the Air Force Institute of Technology, Civilian Institutions.

The author wishes to express his appreciation to Dr Leon Kazarian and Mr Pat Roberts of the Biodynamics Effects Branch, Armstrong Aerospace Medical Research Laboratory and to Mr Tom Collins, Mr Lou Muhic, and Mr Jim Simpson of the University of Dayton Research Institute for not only providing funding, equipment, and a facility to perform my research, but also for ensuring the study was done correctly.

Since the content of this dissertation should be of interest to a wide range of people involved with the design, test and evaluation, and use of cockpits and aircrew seating, this dissertation has been produced as an AAMRL technical report. This document does not follow standard technical report format since it was originally a dissertation.

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CHAPTER I

INTRODUCTION

During the twentieth century, Western Man has transitioned from a working environment which requires an upright stance to one which predominantly relies on seated work, making the chair one of industrialized man's most important tools (Mandal, 1976). Mandal further suggests that as the number of individuals required to work in a seated position has increased, so has the incidence of back injuries and discomfort.

Lower back pain (LBP) is not a new issue. Studies indicate that LBP has been responsible for a significant amount of the lost workdays in the industrialized work force. Kelsey (1978) reported that back pain was the most common reason for decreased worker performance and reduced leisure activity in U.S. workers under the age of 45 (Svensson and Andersson, 1983). Other studies have reported that LBP plagues 60-80% of the adult population at some point in time, making LBP one of man's most common musculo-skeletal problems (Wilder, Woodworth, Frymoyer and Pope, 1982). One of the major ways that LBP and discomfort arises is through postural and spinal stress which can be induced by improper seating. Wilder

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This dissertation follows the style of <u>Human Factors.</u>

et al. (1982) identified that the presence of and exposure to vibration is also a risk factor in LBP and discomfort.

As seated work became more demanding on the human operator, the need for effective seating became imperative. The task of flying an aircraft was one area which was identified as requiring a better seating system and interface capability. As technology and industrial processes continued in rapid advancement, man consciously or unconsciously adapted to his changing environment as he had done throughout his evolution. This evolutionary adaptation process has led man to create larger, faster and more technically sophisticated machines and equipment to cope with environments which he experiences. However, new external conditions have been artificially created as a result of man's evolutionary desire to increase the power and speed of the equipment and machines he has developed. Previously insignificant individual environmental factors have subsequently been altered, therefore markedly increasing their individual and combined significance to human life (Frolov, 1981).

In 1951, the increased capability of Air Force aircraft made it feasible to refuel inflight, thus providing the ability to increase the duration of the mission and also prolong the exposure of the aircrew to

the flight environment. With this technological advancement came the realization that comfort was a serious problem (Whittenberger, 1959). Thus attention to design of aircrew seating was necessary. The problem was further compounded by requirements which insisted that the pilot not leave his seat except for operational reasons (Hawkins, 1974). The recognition of this problem brought about changes in design guidelines to further enhance the seated comfort and performance of aircrew members. Better designed seats, as envisioned, would reduce the fatigue and discomfort associated with extended operational missions. According to the Aircraft Crash Survival Design Guide;

> the comfort of an aircraft seat is a safety-of-flight factor rather than a crash-safety-design factor. An uncomfortable seat can induce pilot fatigue in a short time. Pilot fatigue is an indirect cause of aircraft accidents. Comfort is thus of primary concern and must not be unduly compromised to achieve crash safety" (Desjardins and Laananen, 1980).

It is the primary function of the crew seat to provide comfort, adjustment, and additional support which help the crew member accomplish operational responsibilities (Desjardins, Laananen and Singley, 1980). Despite current guidance, evidence suggests that aircrew members continue to sustain an abnormally high incidence of back

and gluteal (buttock) pain, indicating that the problem has persisted. Fitzgerald and Crotty (1972) reported that LBP in aircrew was significantly higher than that of the ground crew and that the incidence among pilots was significantly greater than that of navigators and all other aircrew members combined. Over half of the aircrews indicated that the major cause of the discomfort and pain was the flight environment (seat, seat harness, flight clothing assembly, and surrounding cockpit) (Fitzgerald and Crotty, 1972). From a pilots' comfort and performance viewpoint, it appears that many existing seats still do not meet basic minimum requirements and hence the questions of seat design is of critical importance (Hawkins, 1973).

The application of human factors engineering to the realm of aerospace design is not a new or unique concept, however its direct application to aircrew seating to solve pilot performance, discomfort and fatigue issues has largely been overlooked. Similar to data gathered during extended seated operations (Congleton, 1983), aircraft aircrew members experience muscular fatigue and discomfort during long duration flights in the:

1. Neck
2. Upper back
3. Mid back

4. Lower back
5. Buttocks
6. Thighs

In order to satisfactorily cover areas which are of interest when embarking on a dissertation topic of such broad scope and depth, it is necessary to develop overall goals to help keep the thrust of the research headed in the correct direction. The overall goals of this dissertation are to:

1. Develop transport/cargo aircrew seat design guidelines.
2. Develop two prototype/modified transport/cargo aircrew seats based upon the neutral body position concept.
3. Evaluate the newly designed prototype aircrew seats by comparing and contrasting them with the currently available aircrew seat, using a simulated aircraft environment and pilot tasks.
4. Utilize seat pan pressure measurement, subjective surveys, human performance measurement and spinal creep measurement to contrast the aircrew seats.

CHAPTER II

LITERATURE SEARCH

INTRODUCTION

The desire to rapidly travel over long distances has resulted in the design and construction of effective, high speed transportation equipment which reflects technology specifically created for this purpose. The problem of protecting man and ensuring that he is being provided a suitable and effectively designed workstation from which to function has become paramount (Frolov, 1981). In the military flying community, the concern for comfortable and effective pilot seating has become a major issue.

It is interesting to note that in the literature, Hawkins (1974) outlines many "sources of trouble" for aircrew members. He states that there are many discomfort or inconvenience factors, some which lead to buttock and lower back pain (lumbar pain), and blood circulation difficulties (high buttock-thigh pressures), while all certainly directly contribute to emotional irritation and arousal. The factors are often associated with poor design in the following areas (Hawkins, 1974):

1. Seat pan height from floor (of primary importance)
2. Height and adjustability of armrests
3. Backrest recline adjustability (this also influences the spinal curvature)
4. Seat cushion and cover material characteristics, particularly ventilation
5. Seat cushion hardness (this also influences pelvic rotation)
6. Seat cushion contouring
7. Seat pan contouring
8. Footrest facilities
9. Pressure distribution
10. Seat rigidity
11. Seat controls
12. Seat/rudder pedal/column control/reference eye position/geometry
13. Ingress and egress
14. Headrest facility
15. Seat belt and harness

PRIMARY AIRCREW SEAT DESIGN CONSIDERATIONS

As noted by the Aircraft Crash Survival Design Guide (1980), several environmental and operational factors other than those associated with crashworthiness affect

the design of an adequate seating system. Because of their importance, the following areas must be investigated as part of the overall development of a design for a new aircrew seat. The areas are:

1. Comfort
2. Seat adjustment
3. Seat pan cushions/backrest cushions
4. Headrest

Comfort

Several factors, including vibration, influence seated comfort. The following list is a summary from the Aircraft Crash Survival Design Guide:

A. Maintain adequate body angles and load distributions.
    1. Thigh tangent angles and backrest angles are influential in body comfort.
    2. Ensure backrest angle of 13 degrees or greater, thus reducing the moment and moving the center of gravity (CG) back.
    3. MIL-STD-1333 requires a thigh tangent angle of 5 to 20 degrees, however angles above 10 degrees tend to rotate the pelvis to the rear, reduce the forward

moment of the spine and tend to effectively move the CG aft.

B. Width of the seat pan

1. Maximum seat pan widths should be provided with the space available.
2. Seat pan should be at least 18 inches wide with 20 inches being desirable.
3. Too narrow a seat pan can exert lateral forces on the side of the body or force the body to be held forward out of the constraints of the seat pan, thus increasing discomfort.

C. Seat pan surface area

1. Seat pan surface area should spread the contact load over the largest area possible, thereby decreasing high pressure points and preventing restriction of blood flow in these areas.
2. Thick, soft cushions or netting should <u>not</u> be used since the low spring rates make them extremely hazardous in crash situations.
3. Cushions being used must provide adequate distribution of loads but not allow excessive motion during crash loading.

D. Thermal ventilation

1. Thermal ventilation for seat cushions is particularly important in hot, humid climates.
2. Close contact between the buttock or the back and interfacing cushion can result in an elevation of temperature coincident with collection of moisture through perspiration.
3. Provisions should be made to carry the hot, humid air out of the interface area via air circulation.

Seat Adjustments

Although passenger seats are typically not adjustable, aircrew seat adjustability is mandatory. Adjustment is necessary due to the design of the cockpit and crew area for the 50th-percentile (stature) male operator. Pilots larger or smaller than the 50th-percentile would not be able to efficiently interface with the cockpit if adjustability were not provided. The following is a summary of Aircraft Crash Survival Design Guide (1980):

A. Enable each user to adjust his eye position to the optimum point.

1. A $\pm$ 2.5 inch vertical adjustment from the neutral seat reference point is required to account for occupant variation.

2. A $\pm$ 2.5 inch fore-and-aft adjustment is required to allow the desired repositioning of the eye and for locating the occupant at the proper distance from controls, pedal, displays, etc.

B. Human factors should be considered in the design of adjustments.

1. Mechanisms should be easy to locate.
2. Mechanisms should be easy to use.
3. Adjustment motions should be precise, allowing the occupant to easily get into a comfortable position with little distraction.
4. Efficient verification that the seat is firmly locked into position should be provided.

Seat Pan Cushions/Backrest Cushions

The aircrew seat pan and backrest should be designed so that it affords the user comfort and durability during the periods of contact. The following is a summary of

the requirements from the <u>Aircraft Crash Survival Design Guide</u>:

A. The compromise between crash safety and user comfort

   1. Provide sufficient cushion thickness to preclude body contact with the seat pan or backrest structure when subjected to specified operational or crash loads.
   2. Provide a means of tightening the fabric on the seat pan or backrest if sagging of the material is a problem.
   3. Use a cushion base with a contour that matches the universal buttocks configuration as closely as possible.
   4. Use rate-sensitive foam to provide a contour transition softer than the base.
   5. A layer of soft, open-celled foam can be used on top of the rate-sensitive foam to provide initial comfort.
   6. Limit the thickness of the compressed cushion from 0.5 to 0.75 inches at the buttock reference point.
   7. Lumbar supports, particularly those that are adjustable by the pilot, are desirable for comfort and safety reasons.

B. The optimum aircraft seat pan/backrest cushion should meet these crashworthy characteristics.

1. Be extremely lightweight.
2. Possess flotation capabilities.
3. Be nonflammable.
4. Be nontoxic; will not give off fumes when burned, charred, or melted.
5. Be tough and wear resistant.
6. Be easily changeable.
7. Provide comfort by distributing the load and reducing or eliminating load concentrations.
8. Provide thermal comfort through ventilation.
9. Provide little or no rebound under crash loading.
10. Allow an absolute minimum of motion during crash loading.

Headrest

According to Desjardins and Laananen (1980), a headrest should be provided to protect the pilot from whiplash. Cushioning of the headrest prevents backward flexure of the neck when impacted by the pilot's head. This cushioning effect can be provided by a thin pad on a

deformable headrest or by a thicker cushion (at least 1.5 inches) or a more rigid structure.

VIBRATION

Although vibration studies began at the beginning of the century, it was not until the 1930's when vibration work began in earnest. This effort was due largely to increased military and transportation requirements of the time (Bryce, 1966). From its earlier stages of primarily automobile and railroad research, vibration study has increasingly been applied to aerospace applications where high-speed flight imposes significant stresses on the human operator.

Bryce (1966) has stated that, in general, there are essentially three categories to classify the effects of exposing humans to mechanical vibration. The first involves medical studies which include psychological factors as well as physiological, bio-dynamic and pathological responses of the body. The second category involves subjective testing of the participant to obtain personal comment or judgement. Studying the effects of vibration on task performance is the third area of study. Because these three approaches are not necessarily independent, the results of the same physical phenomenon should qualitatively support each other (Bryce, 1966).

According to Guignard and King (1972):

> Aerospace operation, and particularly military flying, can occasion some of the worst conditions of vibration to which man is exposed. Appreciable vibration is nearly always present to some degree in the flight of an aircraft, arising either from the engines and auxiliary machinery in the machine itself or from aerodynamic causes. Vibration and acceleration forces in flight can affect the ease and efficiency with which the aircrew or astronauts perform their tasks; the passengers enjoyment of his journey; and perhaps also the efficiency with which he takes up work or military duties after it. In some circumstances, severe vibration can render a flying task impossible to perform, or cause injury inflight, leading to partial or complete failure of a mission. Low frequency vibration, and especially the motion induced by aircraft responses to gusts, is accordingly recognized as one of the more important physically stressful agents of the aerospace environment.

With the introduction of the jet engine, much of the engine vibration problems have been controlled or isolated due to the shifting of the predominant frequencies to higher ranges. However, in propeller-driven aircraft, unbalanced forces related to engine operation and propeller blade passage create low frequency vibration in the 10 to 1000 Hz range (Guignard and King, 1972). Thomas (1962), in a dynamic vibration evaluation of the Hercules C-130A aircraft, performed five flight tests and collected approximately 50,700 data

points. From the tests, Thomas (1962) determined that the dominant source of vibration frequencies was the propeller. However, vibration frequencies due to engine and accessory unbalance were also major contributors. A frequency range of 15 to 500 Hz was produced by propeller unbalance and blade passage past the fuselage. The intensity of this vibration was greatest adjacent to the propellers and diminished as the distance from the propeller increased (Thomas, 1962).

Human Response to Whole-Body Vibration

Whole-body vibration is a widely spread stimulu which encroaches upon the various body organs simultaneously (Helmkamp, Redmond and Cotlington, 1985). Because of the interest generated, efforts have been made to determine the specific effects of vibration on man in controlled environments. According to Beljan (1972), most aviation related vibration research has been limited to the frequency range of 1-20 Hz. He stated the reasons for this are: (a) manned high-performance aircraft, rocket propelled space vehicles and escape systems involved low-frequency high-amplitude vibrations; (b) mechanical damping systems can protect the pilot from vibrations above 20 Hz; (c) man absorbs most of the

vibration energy, and bodily resonance frequencies occur in the 1-20 Hz frequency range (Beljan, 1972).

A vast majority of the research performed has been collected on human response to Z-axis vibration, that is, motion directed along the longitudinal axis of the body (Figure 1). Vibration studies have further highlighted that the mechanical response of the body to vibrations is greatest in the frequency range from 1 to 20 Hz, and that the greatest transmissibility or whole body resonance occurs around 5 Hz (Coermann, 1961). Above 20 Hz, the soft tissues of the body attenuate the motion, thus localizing the effects to the points of contact with the vibrating surface; whereas below 1 or 2 Hz, the body acts as a rigid mass (Shoenberger and Harris, 1971). Laboratory studies of human tolerance to vibratory stimulation have indicated that in the most critical frequency band (4-8 Hz for the Z-axis), sinusoidal vibration is likely to be physically uncomfortable at acceleration-amplitudes much above 0.1 g; painful or distressing at intensities in the region of 1 g; and injurious at acceleration-amplitudes exceeding 2 g, if sustained for more than a few cycles of motion (Guignard and King, 1972).

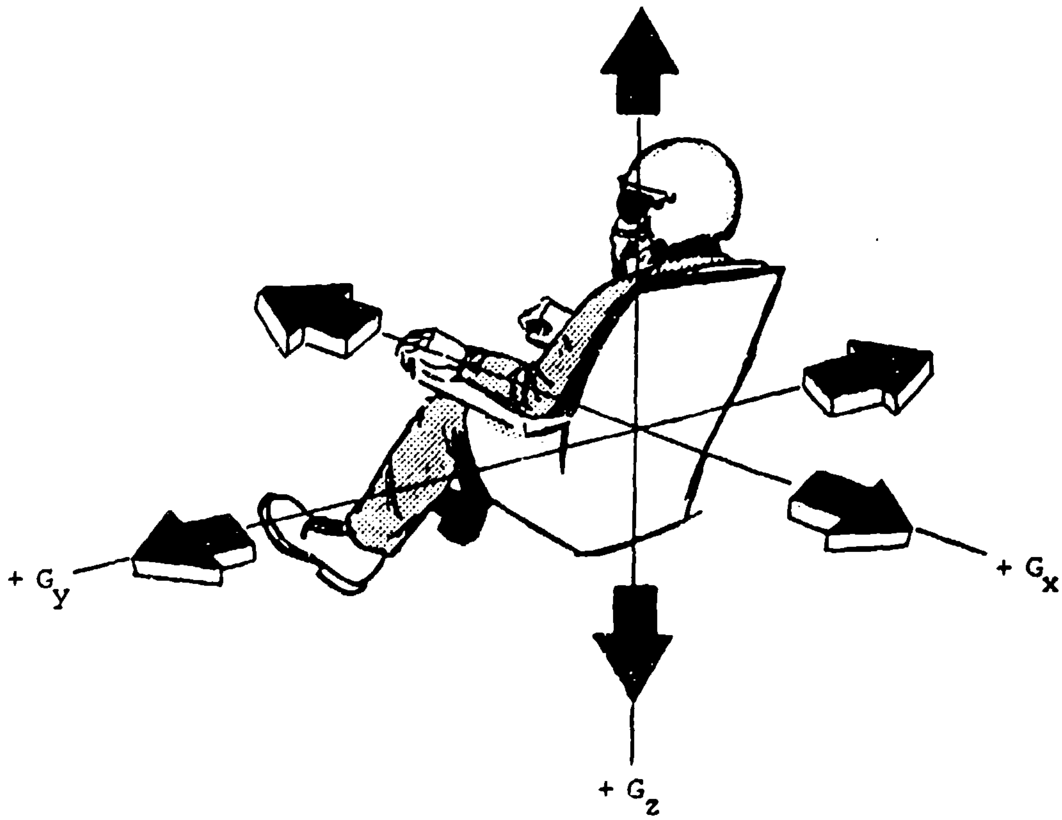


Figure 1. X, Y and Z Acceleration Axes.

Effect on Task Performance

Human exposure to high performance aerodynamic vehicles and the associated vibrational stresses has become a very critical issue when dealing with the aircrew member's ability to successfully perform tasks which are essential to mission completion (Coermann, Magid and Lange, 1963). Lovesey (1981) has identified ten important parameters which can affect human performance. They are:

1. Direction and number of axes of vibration
2. Acceleration level of the vibration
3. Frequency content of the vibration
4. Seat geometry and dynamics, including seat cushion and restraining harness characteristics.
5. Task difficulty
6. Subject's skills and training
7. Subject population
8. Subject's motivation
9. Subject's clothing, e.g. protective headgear
10. Duration of the vibration task

Others, such as Beljan (1972) and Wilkinson (1969), have also recognized these factors as being influential

on the effect of an environmental stressor such as vibration. The presence of these factors, in combination, has been shown to be not necessarily additive; some combinations may act antagonistically upon performance, whereas others may be synergistic in their effect (Grether, 1970; Broadbent, 1963). Guignard and King (1972) have reported that:

> First, vibration - especially heavy shaking or jolting at low frequencies (1-10 Hz) - interferes with the skilled use of hand and eye by forcing differential motion to take place between the man and his point of contact with the task. (It may also alter the normal pattern of integrated neuromuscular activity in the performance of motor tasks). This direct mechanical action of vibration is, in the main, frequency-dependent, and, of course, it also depends upon the intensity (acceleration-amplitude) of the disturbing vibration. It is largely independent of the duration of the disturbance, at least in the short term, supervening immediately upon exposure to the motion. In the long term, opposing effects may modify the action. On one hand, a degree of compensatory adaptation may be seen, in which the man learns to manage his task in spite of the vibratory disturbance. This is more likely to occur when the vibration is constant in quality rather than varying unpredictably. On the other hand, during long exposures (hours) increasing muscular and general fatigue may mitigate against any such improvement in performance.

Despite all of results collected from various research efforts, there really is no simple relationship

between the level of vibration to which an individual is exposed and the resulting level of task performance (Lovesey, 1981). Since most performance measurements have been made in a laboratory employing sinusoidal or near-sinusoidal vibration, the performance results generated have displayed little usable data since the number of unknown or uncontrolled factors made detailed analysis of results nearly impossible (Lovesey, 1981). According to Shoenberger (1975), the majority of vibration effects are measured during tasks which require precise motor response (skilled manipulation of tracking controls, positioning controls, or small switches and buttons) or those which require fine sensory discrimination (obtaining information from visual displays). Only a few studies have been able to attribute effects due to intellectual or cognitive functions. Based upon analyses of various vibration effects, Shoenberger (1975) believes that the predominant mechanism for vibration performance effects is direct mechanical interference with functions occurring in the input and output stages of operator performance tasks. Mackie, O'Harlon and McCauley (1974) noted performance decrements on several tasks requiring visual acuity or pattern recognition. Performance decrements due to vibration have also been frequently found in compensatory

tracking tasks, especially when the tracking task is in the same axis as the vibration (Mackie et al., 1974).

METHODS OF EVALUATING AND CONTRASTING SEATS

"Is the piloting community, then, simply a group of complaining, unfit, unreasonable men, or is there really something in this oft-repeated plea for better ergonomics in crew seat design?" asked Hawkin (1974). Armed with the knowledge that major airlines such as KLM, Air France, BOAC, SAS and Swissair have found it necessary to modify or redesign their aircraft aircrew seats due to inadequate original design, Hawkin's question definitely suggests the need for better aircrew seating. There are many means by which seating can be evaluated and compared. The following techniques are those which can be utilized in seating research. They are as follows:

1. Subjective evaluations
2. Human performance
3. Electromyography (EMG)
4. Spinal creep
5. Postural analysis
6. Disc pressure
7. Pressure points and patterns

Subjective Evaluations

There are essentially two general cases in which subjective measures are utilized. They are: 1.) when behaviors or performances are rated (rating scales) and 2.) when the duration and frequency of behaviors and performances are counted on a sampling or continuous basis (frequency or direct observation) (Meister, 1985). Most of the subjective evaluations which have been successfully used to evaluate seats have employed rating or scaling techniques. Of the subjective techniques used to evaluate seating and, specifically, aircrew seating, various forms of general comfort, body discomfort and chair feature checklists have been used.

In 1959, the Air Force developed a laboratory experiment to evaluate the design features, in terms of human comfort, of five aircrew seats which were being compared for a contract purchase. The study evaluated the various seat components and gathered the subjective input by using a 9 point comfort/discomfort scale, a body discomfort checklist and a seat feature checklist (Slechta and Forrest, 1959). As the Air Force expressed greater concern about the factors which could affect crew fatigue and mission accomplishment, they again turned to aircrew seats. Since poor seating accommodations had been shown to contribute to fatigue and performance

decrements, the Air Force performed a study to define, develop and evaluate specific design characteristics of the C-5A aircrew seats in terms of human comfort (Burson, Watson and Duncan, 1967). This study took into account comfort ratings (9-point scale), body part discomfort/ sensation surveys (6 areas), seat feature checklist (3 point scale) and an extensive discomfort survey. The findings of the study indicated that by using a multi-item questionnaire employing a battery of approaches (comfort ratings, body part discomfort, and seat part evaluations), the relative comfort of aircrew seats could be compared and comfort could be improved by eliminating those areas which were noted as causing discomfort (Burson et al., 1967).

Similar rating scales have been developed to help evaluate normal chairs. Shackel, Chidsey and Shipley (1969) developed an eleven point general comfort evaluation. This comfort scale has been used successfully by Drury and Coury (1982) and Congleton (1983). A body part discomfort scale, which was developed by Corlett and Bishop (1976), was used by both Drury and Coury (1982) and in a modified form by Congleton (1983) in the evaluation of prototype chairs. Several chair feature checklists have also been developed. Shackel et al. (1969) developed a three-point

scale chair feature checklist which was modified by Drury and Coury (1982) to provide more detailed discrimination. Congleton (1983) modified Drury and Coury's version of the chair feature checklist to accommodate unique features of his prototype chair. All checklists were easy to explain, easy for participants to answer and provided the researchers with valuable design information.

Human Performance

It is essential for most human factors engineering research activities to attempt to measure human performance to provide quantitative data to evaluate the man-machine interface. This responsibility stems from the expectation of realistic objective data to add credibility and validity to subjectively collected data. In the area of seated research, it has been extremely hard to quantify significant changes in human performance as a function of seating (Drury and Coury, 1982). Other research suggested that the seat has to be incorrectly adjusted and perceived as uncomfortable before any noticeable performance decrements were observed (McLeod, Mandel, and Malvern, 1980). Congleton (1983), however, reported statistically significant differences between

chair postural treatments when using the pursuit rotary tracking task as the human performance measure.

Human performance tasks have long been used to document human capabilities and limitations.

> When one attempts to answer questions about human performance as it occurs in operational situations, one becomes painfully aware of the inadequacies of the extrapolations that must be made in attempting to apply research data to the practical problems of the real world. And when one attempts to design research to attack such questions--either specifically or in general--one becomes painfully aware of the absence of a body of generally accepted experimental methodology. For there is, in fact, no methodology that is generally accepted by those who ultimately make decisions about the implementation of the resultant recommendations (Chiles, 1967).

The significance of this statement, designed to examine human performance, can be seen if it is compared to the state of affairs which would exist in the medical field should there be no readily acceptable methodology for clinical evaluations and no adequate theories to interpret the results of the clinical tests performed (O'Donnell, 1972). Fortunately, test batteries have been developed for the express purpose of placing selective demands on the elementary mental, motor and information processing functions of the human operator. The Criterion Task Set (CTS) is such a test. The theoretical basis and standardized features of the CTS make it potentially applicable to a number of real world research

problems in the area of human performance assessment and human factors. Currently this battery consists of nine standardized tasks which are contained on user-friendly software (Shingkedecker, 1984). Another test battery, the NASA sponsored Automatic Performance Test Systems (APTS), was designed to examine human performance under unusual and atypical environments. This battery provided tests which are stable, sensitive and related to the tasks to be performed under operational conditions (Wilkes, Kennedy, Dunlap and Lane, 1986).

Electromyography (EMG)

The measure and quantification of muscle activity and fatigue has become increasingly important in the realm of man-machine interface. A routinely used tool for the non-invasive measurement of muscle tension and degree of muscle fatigue is the electromyogram (EMG). Essentially, the electromyogram measures the muscle electrical activity (complex motor unit potential) created by the combination of several muscle fiber action potentials by means of an electrode. The recorded EMG voltage, called the myoelectric activity, is the sum of several motor unit potentials (Chaffin and Andersson, 1984). There are two types of electrodes used to measure the myoelectric activity: intramuscular, which is a

needle electrode inserted into the muscle, and skin surface electrode, which is a flat conductor attached on the skin above the desired muscle group.

Electromyography has been used with a varying amount of success in a number of different experiments. In a static environment, the electromyograph has been effectively employed to estimate the stress encountered while muscles performed a number of different functions (Johnson, 1978). EMG has also been used at the Air Force Aerospace Medical Research Laboratory (AFAMRL) for muscle fatigue evaluation during acceleration exposure. The EMG signal was able to provide significant objective data information for evaluating muscle fatigue. However, the reproducibility of data, especially in the dynamic environment, proved to be a significant challenge (Luciani, Ratino, McGrew, and Suiza, 1983). Wilder et al. (1982) collected EMG signals from the erector spine and external oblique and observed a wide variation of EMG activity of males and females with respect to body posture. Because of the wide scattering of data, none of the variations proved significant. Additionally, subjects were measured to determine the fatiguing effect of vibration over a 30-minute period. Although there was no change in the myoelectric activity during the statistical period, when the subjects were vibrated, the

raw EMG data demonstrated a shift from higher frequency to lower frequency, suggesting a fatigue of the muscle due to vibratory exposure (Wilder et al., 1982).

Measuring EMG under isometric, static conditions is reasonably reproducible however, under dynamic conditions, the validity of the results is uncertain (Chaffin and Andersson, 1984). EMG results from day to day and from one laboratory to another are often ambiguous or contradictory (Lippold, 1967). Since the electrical activity which the electrodes pick up may originate well away from the electrode placement site, surface EMG may present activity from muscles which are both relevant and irrelevant to the desired measurement (Basmajian, 1967). The use of EMG is also severely restricted due to the large differences in both the amplitude and frequency components between subjects and at different times for the same subject. Furthermore, environmental factors, such as temperature, can shift the EMG spectra outside its specific range since muscle temperature can effect the frequency components of the EMG (Chaffin and Andersson, 1984). Because so many factors can influence the results provided by muscle activity, great care must be exercised when using EMG to predict muscle contraction levels, especially in dynamic environments.

Spinal Creep

In the human body, the vertebral column acts as a stability structure for the maintenance of the upright body position. In this role, it is subject to a variety of different forces and stresses of complex nature (Morris, Lucas and Bresler, 1961). From the axis to the sacrum, there are twenty-three intervertebral discs which are located between the individual vertebra and unite the spine (Kapit and Elson, 1977). The intervertebral discs, combined together, account for approximately 33 percent of the total vertebral column length. They also are a significant help in the attenuation, transmission and distribution of loads (Kazarian, 1975). A general finding reported by Kazarian (1972) concerning the nature of the invertebral disc was that the disc exhibited elastic-like properties which are typically retained throughout life. Therefore, under axial loading conditions, although the intervertebral disc loses height, it usually will resume its normal height after a recovery period. Whenever the compressive loading exceeds the osmotic pressure of discal tissues, fluid is expelled. Thus, the effects of static and dynamic loading are of major importance in the study of back symptoms and back injury (Tyrrell, Reilly and Troup, 1985).

Although there have been many excellent presentations of the problems associated with sitting, there has been a lack of information relating the anatomical and physiological causes of lower back and buttock pain to seating and the subsequent redesign corrections necessary to eliminate these problem areas. Indeed, little scientific study has been performed by chair or seat manufacturers to identify the pathological factors involved in low-back complaints related to seating (Keegan, 1953). It appears that recently acquired knowledge of the pathology of intervertebral discs should be applied to the seating problems so as to enhance the design of seats for the many people with low-back pain and for those normal persons who tend to develop symptoms of low-back pain from sitting (Keegan, 1953).

Spinal creep is defined as the acceleration of creep (of the spinal column) under a compression bias (Kazarian, 1972). There has been sufficient information, from experiments in which intervertebral discs were excised from cadaver subjects, to indicate that the application of longitudinal static and/or cyclic loads causes spinal creep. Vibrocreep, defined as the acceleration of creep under a compression bias and an additionally superimposed vibratory load, is a recent

area of study and therefore contains little or no information (Kazarian, 1972). In an attempt to understand more fully the practical importance of vibrocreep, various experiments were performed by Dr. Kazarian. From the experiments, a number of qualitative observations were made (Kazarian, 1972):

1. Creep under vibration was different for different vertebral units within the spinal column.
2. The larger the excursion peak to peak amplitude, the greater the creep.
3. Upon removing the posterior vertebral arches, the tendency to creep was greater, but very much age-dependent.

According to Dr. Kazarian, vibrocreep was probably an intermediate response, rather than the subsequent response, between the applied compression loading and the dynamic vibration loading; however, further qualitative information was needed before useful quantitative information was available (Kazarian, 1972).

Later research performed by Kelsey (1978) indicated that individuals who were exposed to vibration and long-term exposure to automobiles and trucks had an increased incidence of lower back and buttock pain, and herniated

discs. The results of this experiment tied in quite well with the finding which Kazarian reported and helped to solidify the link between spinal creep and low-back pain resulting from long term sitting and vibration exposure. Further research, involving 3500 participants, indicated that individuals exposed to vibration (eg., truck and tractor driving and heavy equipment operation), complained of buttock and low back pain more often than those not involved (Frymoyer, Pope, Rosen, Goggins, Wilder and Constanza, 1980).

A technique was developed by Eklund and Corlett (1984) to accurately measure the variation in stature due to spinal loading. The method was sensitive enough to show consistent effects on stature due to carrying loads and could distinguish the effects of sitting in chairs of different designs (Eklund and Corlett, 1984). A comparable method of stature measurement was employed by Tyrrell et al. (1985). The results of the experiment indicated that the method could be used quite successfully in assessing spinal loading with a variety of ergonomic, occupation and therapeutic applications.

Pcsture Analysis

It is imperative for the designer or researcher involved in seated research to be familiar with various

techniques to measure and quantify the forces experienced by the seated operator. This provides useful information for design with respect to operator discomfort, and additionally helps to isolate specific problem areas associated with different seated positions.

Sitting is a posture whereby the body weight is supported by the ischial tuberosities and the surrounding soft tissues. Depending upon the posture adopted and seat design, a percentage of the body weight is transferred to the work surface, armrest, back cushion and ground (Andersson, 1985). According to Andersson (1985), there are many advantages associated with the sitting posture over standing. They are:

1. Provides necessary stability for specific tasks.
2. Consumes less energy.
3. Imposes less stress on lower extremity points.
4. Decreases hydrostatic pressure to improve lower extremity circulation.

For these reasons, seated posture is an important consideration for design.

Several techniques for measuring seated postures are contained in literature. Colombini, Occhipinti, Frigo, Pedotti and Grieco (1985) reported that by using a

piezoelectric force platform, lateral viewing TV camera, a signal detection device (Digivee) for the platform and retroreflective markers applied at the main "repere" points of the subject, they were able to perform postural analysis on ten subjects. From the data collected they were able to determine the lumbar (L3/L4) and cervical (C6/C7) intervertebral disc loads for each subject and posture (Colombini et al., 1985).

Another technique used for postural analysis is based on using gravity pendulums attached to electrical potentiometer to continuously measure postural angles. Results indicated that there was a correlation between postural angles, however the correlations depended upon factors not mentioned in the study. (Aaras, Westgarrd and Strander, 1987).

Christensen, Casali and Kroemer (1984) reported the use of yet another postural assessment technique. The technique was used, in this case, to define the posture of seated subjects. This method entailed recording the movement of the torso, head and each limb on concentric circles when they deviated from the original base line measurement. This provided information in the transverse plane. Movements in the sagittal plane were recorded on coded radial lines. The technique worked well and was

easy to perform after modest training (Christensen et al., 1984).

Disc Pressure

Since a seat should not only be functional but should alco reduce the postural stress on the body, data should be collected to address postural stress. Measurement of intradiscal pressure is a technique to assess postural stress. Intradiscal pressure is typically measured inserting (in vitro) a sub-miniature pressure transducer, built into the top of a needle, into the center of an intervertebral disc (Andersson, 1980).

In a study performed with both intradiscal pressure and EMG measurements, disc pressure and EMG activity changed with various seated positions and when various back supports were applied (Andersson and Ortengren, 1974).

Later studies indicated that inadequate sitting and standing postures excessively increased the intradiscal pressure. Disc pressure can be gradually lowered as the backrest angle of the seat is increased. At angles between 110-130 degrees, the intradiscal pressure is lowest due to relaxation of the back muscles (Grandjean and Hunting, 1979).

Andersson (1985) compiled the findings of his and other researcher's experiments concerning intradiscal pressure and reported that:

1. An increase in backrest inclination reduces disc pressure due to load transfer to backrest.
2. The deformation of lumbar motion segments can be reduced by using lumbar support to increase lumbar spine lordosis.
3. Disc pressure can be reduced by using armrests to support the arms.

Pressure Points and Patterns

Congleton, Ayoub and Smith (1985) reported that the technique of measuring buttock and thigh pressure points and patterns, while seated, had received very little, if any, use in the past twenty years. Hertzberg (1955) was the first to investigate this technique as a means to acquire data to develop seat design criteria.

When an individual sits down, the body weight displaces the flesh on the buttocks and thighs. As the flesh cells are compressed, especially near the ischial tuberosities (hard bone protrusions at the bottom of the hip), the nerves and blood supply are restricted (Hertzberg, 1955). When seats are properly designed,

they distribute the weight of the buttocks, thighs and tuberosities over the area of the seat pan. This is reflected by lower pressure readings on a specially calibrated pressure pad and sensor. Congleton et al. (1985), was able to show significant differences between buttock and thigh pressure points on the six treatments he employed in his study. Further study by Congleton has indicated that this is a very useful tool to evaluate and optimize seat design and to detect potential seat pan discomfort.

RESEARCH OBJECTIVES

Based upon the information available and the interest generated, the purpose of this research is to examine and identify a means of reducing or eliminating pilot discomfort, while enhancing performance during the span of the mission. Therefore, the objectives of this research are to:

1. Determine which aircrew seat allows the best human performance in the vibration environment.
2. Determine which of the three aircrew seats provides the most comfort to the aircrew members as measured by the Aircrew General Comfort Rating questionnaire, Aircrew Body Part

Discomfort Survey and the Aircrew Seat Feature Checklist.

3. Determine which aircrew seat is most preferred, after experiencing all three, as measured by the Post Test questionnaire.

4. Determine if there were any spinal contour differences among subjects after experiencing each of the three aircrew seats.

5. Determine which aircrew seat provides the lowest maximum seat pan pressures.

CHAPTER III

AIRCREW SEAT STUDY

METHOD

In order to define and evaluate the current problems in fixed wing aircraft aircrew seating, an aircraft was selected which exhibited major ergonomic seating problems and was readily available for testing and evaluation. Although ejection seats were not without their own problems, the current seating problems experienced in transport/cargo aircraft with non-ejection seats were deemed more suitable for an initial investigation in aircrew seating problems. Of the cargo/transport aircraft currently in the United States Air Force's inventory, the pilot seat in the Lockheed C-130 Hercules was a prime candidate due to:

1. The extensive time the C-130 has been operational without major modification to its existing aircrew seats.
2. The actual number of C-130 Hercules still used in operational flying duties in the various military branches (USAF, Navy, Army, Marines), Reserve Units, Coast Guard, and Air National Guard.

3. The long duration of the actual operational mission (average mission length - five hours).
4. The relatively high vibration exposure created by the four (4508 hp) Allison T56-A-15 turboprop engines, combined with the surrounding external environment.

As a means of identifying and evaluating current aircrew seating problems experienced in cargo/transport aircraft, and specifically in the Lockheed C-130 aircraft (Figure 2), the following measures were implemented:

1. Review AMI C-130A aircrew seat design.
2. Collect information concerning C-130 aircrew seats currently being used in operational flying missions.
3. Gather inflight and post-flight data relative to the design and comfort of the current C-130 aircrew set.

Discussion of Previous Aircrew Seat Design

The current AMI C-130 aircrew seat pictured in Figure 3 is representative of many transport/cargo aircraft aircrew seats being utilized in the current military flying scenario.

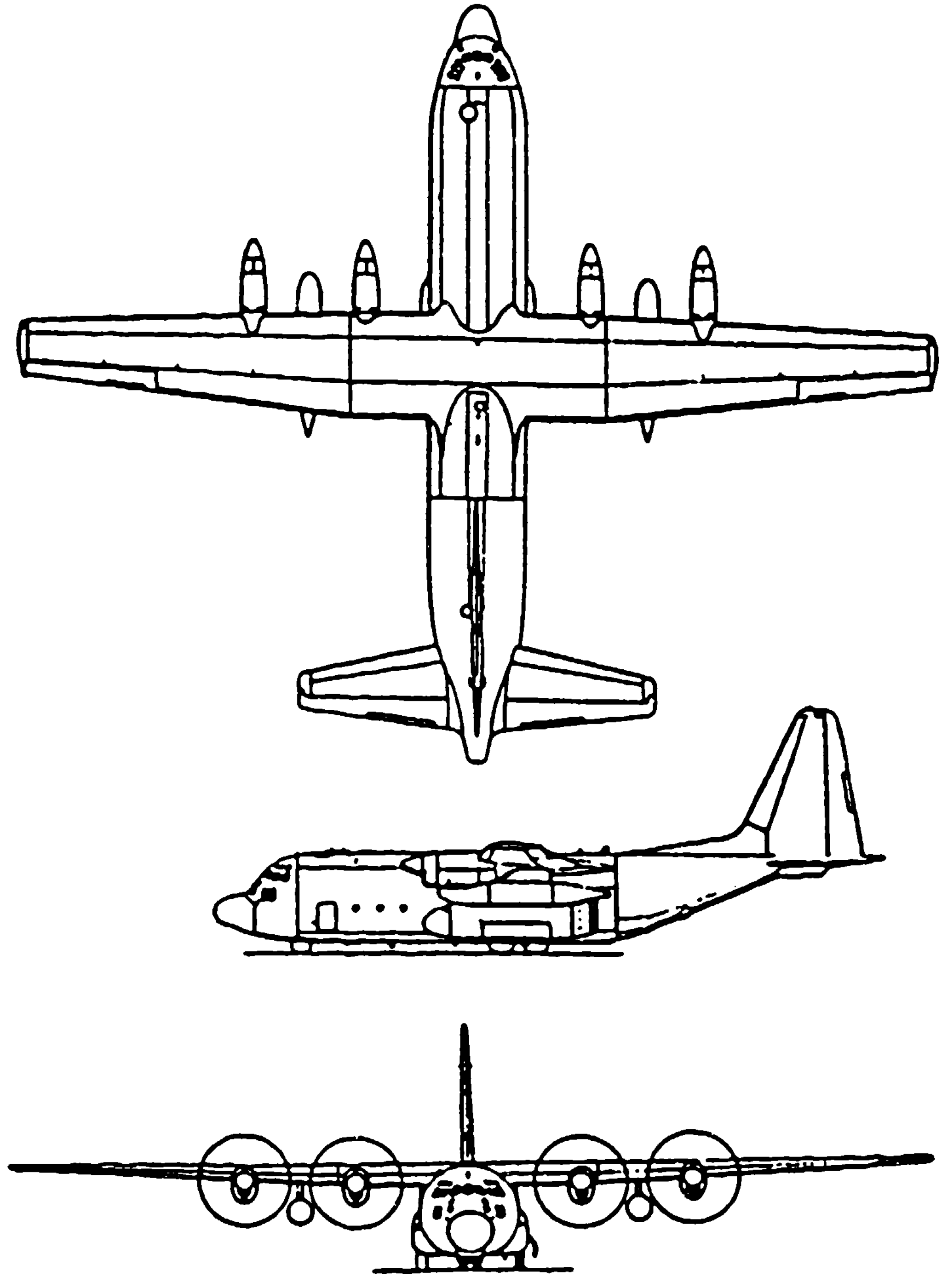


Figure 2. Lockheed C-130 Hercules.
(Adapted from Taylor and Munson, 1985).

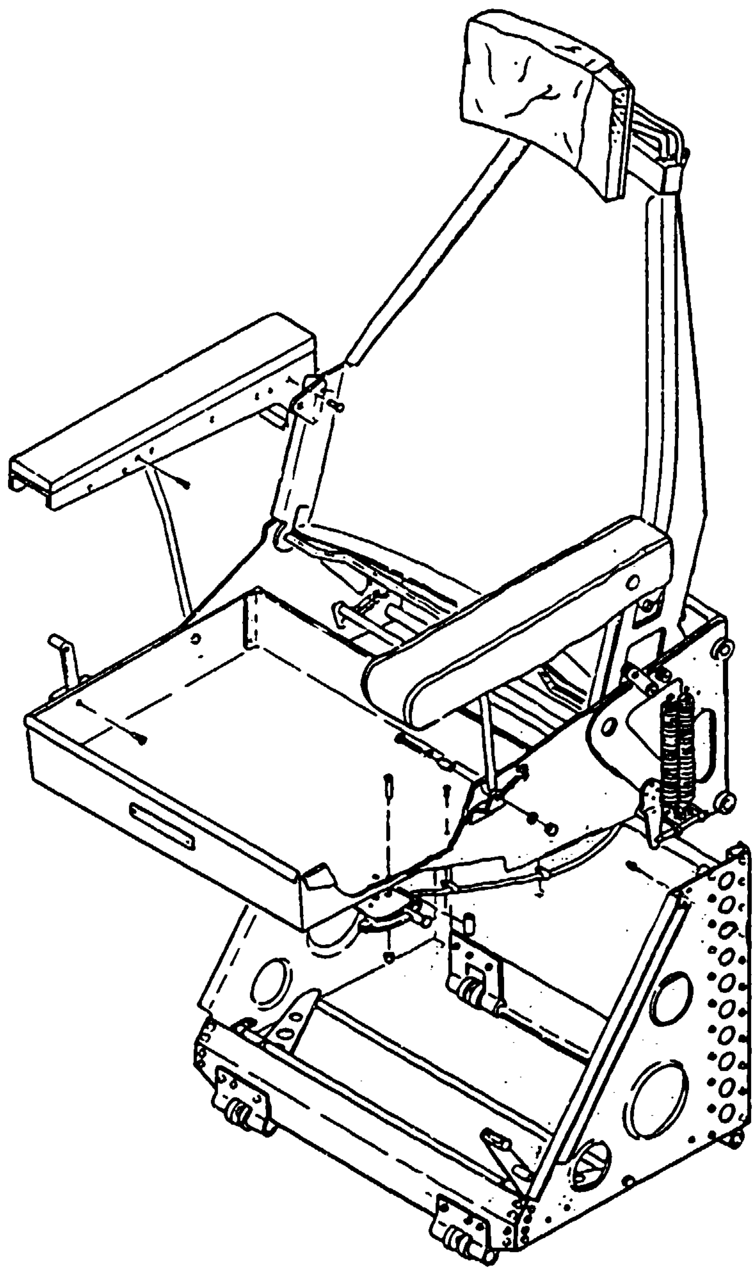


Figure 3. The Current AMI C-130A Aircrew Seat.
(Adapted from Department of Defense, 1972).

Notable features of the aircrew seat are:

1. Stationary headrest with polyurethane foam padding.
2. Triangular backrest which supports the foam back cushion.
3. Polyurethane foam backrest cushion overed with orange, fire-resistant material.
4. Armrest assemblies with hand operated, adjustable locking up or down positions.
5. Square bucket assembly which retains aircrew seat cushion.
6. Seat cushion consisting of a styrofoam base with a polyurethane foam pad on top, encased in an orange, fire-resistant cover.
7. Crew restraint lap belt (Figure 4).
8. Vertical metering control assembly for up and down positioning of seat pan and backrest.
9. Reclining control rod assembly for adjusting the backrest to a desired position.
10. Right triangular base assembly designed for crash-worthiness and structural integrity.
11. Horizontal metering control assembly for fore and aft movement along a seat rail mounted to the floor of the cockpit.

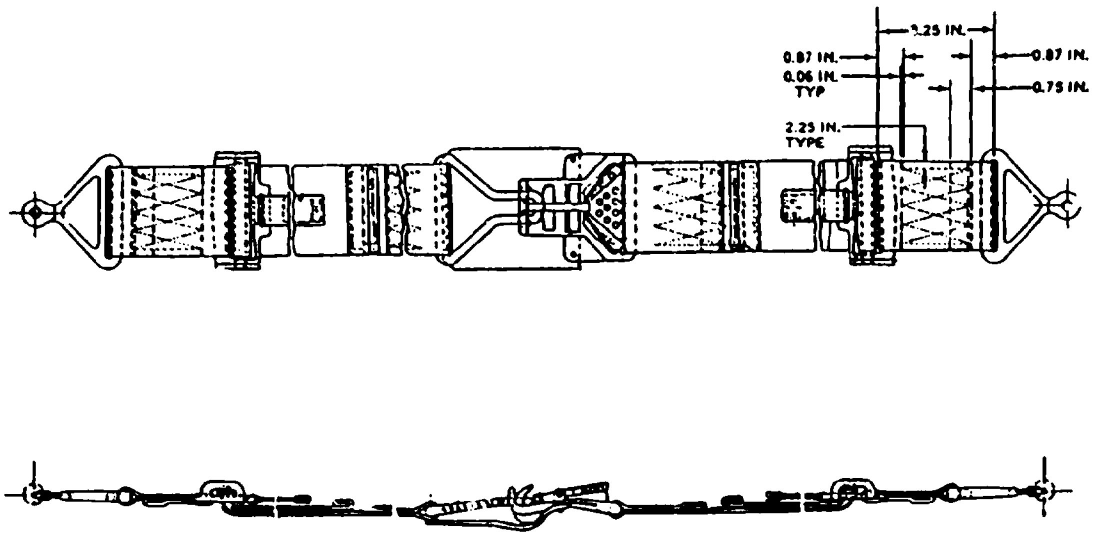


Figure 4. C-130 Crew Restraint Lap Belt. (Adapted from Department of Defense, 1971).

Through in-depth observations of the cockpit area and detailed conversations with transport/cargo aircraft pilots, seven strengths and weakness were noted in the current aircrew seat design. They are as follows:

1. The stationary headrest is designed such that it will stop the head during an abrupt maneuver or crash landing. However, as a support during flight operations, it is essentially useless for a majority of the pilots, due to its lack of adjustability. The pilots seldom used the headrest.
2. The triangular backrest does not support the shoulders due to the narrowness at the top. This, consequently, causes the pilots to tend to roll their shoulders forward, thus increasing the muscle strain in the trapezius and deltoid muscle groups.
3. Since the seat pan for the aircrew seat is essentially a square box, a means of ensuring that the pilot did not hit the lip of the pan, while flying, had to be developed. This problem was "fixed" by developing a cushion that consisted of two parts. The first part was a styrofoam base which raised the level of the seat surface four and three-eights inches. On top of

this square of styrofoam was placed a two to two and three-fourths inch deep square pad of polyurethane foam. This all was encased in a seat cover. There were several problems encountered with this seat cushion design.

a) The seat cushion was uncomfortable after 2 hours (regardless of age of cushion).

b) After the foam cushion had been used for a short period, the foam was no longer resilient.

c) Since highest pressures are generally directed over the ischial tuberosity areas, this portion of the foam pad began to rapidly deteriorate.

4. The armrests were used by a majority of the pilots to relieve muscle stress and tension while performing routine, high altitude flying. The ability to quickly disengage the armrest and move it out of the way during turbulent, low altitude, tactical maneuvering was an asset that most individuals desired.

5. The vertical metering (adjustment) control assembly, the horizontal metering (adjustment) control assembly and the reclining control rod

assembly were all essential in providing the pilot the ability to adjust the aircrew seat such that it was comfortable for him. They were all used frequently, however most of the adjustments were made prior to takeoff.

6. The base assembly had the advantage of being designed to be light-weight, yet strong enough to endure a 9-G crash without exceeding the tensile strength.
7. The foam in the backrest cushion was of sufficient thickness, however a vast majority complained that (there was little or no lumbar support and therefore) they experienced back pain during most flights.

Seat Feature Checklist Results

To collect data concerning the current C-130 aircrew seats, sixty-five C-130 aircrew members were asked to evaluate their current seating accommodations using the Aircrew Seat Study Chair Feature Checklist. This was a modified version of Congleton's (1983) and Drury and Coury's (1982) Checklist. Figure 5 presents the results of this survey. The following general comments can be made in regard to the current C-130 aircrew seat features as a result of this survey:

AIRCREW SEAT STUDY
Modified Chair Feature Checklist

Instructions

Below is a list of chair features which contribute to comfort. On the right hand side of the page, opposite each feature, are three brief phrases descriptive of the feature. Mark on the line with an "X" at a point which describes the opinion you have of that feature. The endpoints of the lines are the extreme cases. Be sure to put only one "X" on each and every line.

Feature			
SEAT:			
Seat height above the floor. (amount it can be adjusted)	too low	correct	too high
Seat length.	too short	correct	too long
Seat width.	too narrow	correct	too wide
Slope of seat.	slopes too far towards back	correct	slopes too far towards front
Shape of seat.	poor fit	adequate	fits well
Padding in seat.	needs more	adequate	needs less
BACK SUPPORT:			
Position of backrest.	too low	correct	too high
Chair back.	poor fit	adequate	fits well
Curvature of back support.	too flat	correct	too curved
Padding in chair back.	needs more	adequate	needs less
OVERALL:			
Material used to upholster the chair.	dislike	indifferent	like very much

INITIALS ______________

DATE ______________

*** PLEASE WRITE ANY COMMENTS (LIKES OR DISLIKES) CONCERNING THE SEAT ON THE BACK OF THIS FORM

Figure 5. Results of Aircrew Seat Study Chair Feature Checklist. (Presented Using Means and Standard Deviations).

1. Seat height adjustment was essentially correct, although the pilots tended to adjust their seats too low.
2. Seat pan length was judged to be slightly too short.
3. Seat pan width was perceived as a little too narrow.
4. Slope of the seat was essentially correct, tending towards a slightly forward slope.
5. Pilots indicated that the seat pan was a poor fit and required redesigning.
6. The seat pan needed more padding.
7. Position of the backrest was correct.
8. The triangular backrest was judged by the pilots to be a poor fit and was in need of modification or redesign.
9. The backrest was judged to be too flat.
10. The backrest needed more padding.
11. Pilots disliked or were indifferent to the material used on the seat pan and backrest cushions.

General Comfort Rating Results

The general findings of the Chair Feature Checklist were supported by data collected inflight in which forty

aircrew members reported how comfortable they felt in their seat, at one hour intervals, during the duration of the flight. This data was collected using the General Comfort Rating (Figure 6), which was developed by Shackel et al. (1969) and is previously described in Chapter II. As depicted in Figure 7, the comfort level of the flyers steadily decayed from an initial feeling of comfort to feeling numb (on pins and needles) by the end of a five hour training mission.

Body Part Discomfort Survey Results

As further evidence to help determine if there was, in fact, a seat design problem, Body Part Discomfort forms were filled out by eighty-five aircrew members after completing representative missions. The results of this survey indicated that there was a design flaw within the current seat configuration. As indicated by Figure 8, aircrew members reported pain and discomfort in a number of areas. However, the vast majority indicated that the buttock and lower back areas were the primary area of discomfort/pain and this again reflects back and lends credibility to the previous results.

Although the seat was designed to conform to the appropriate military standards, it appeared that little thought or research was incorporated in areas such as the

AIRCREW SEAT STUDY
GENERAL COMFORT RATING

Instructions: Please mark only <u>one</u> "X" on the vertical line. Place the "X" at a place on the vertical line which corresponds to how comfortable you feel in the chair you are <u>now</u> sitting in.

Please rate the chair you are sitting in on your feelings <u>now</u>.

- I feel completely relaxed.
- I feel perfectly comfortable.
- I feel quite comfortable.
- I feel barely comfortable.
- I feel uncomfortable.
- I feel restless and fidgety.
- I feel cramped.
- I feel stiff.
- I feel numb (on pins and needles).
- I feel sore and tender.
- I feel unbearable pain.

INITIALS ____________

DATE ______________

Figure 6. General Comfort Rating. (Adapted from Shackel et al., 1969).

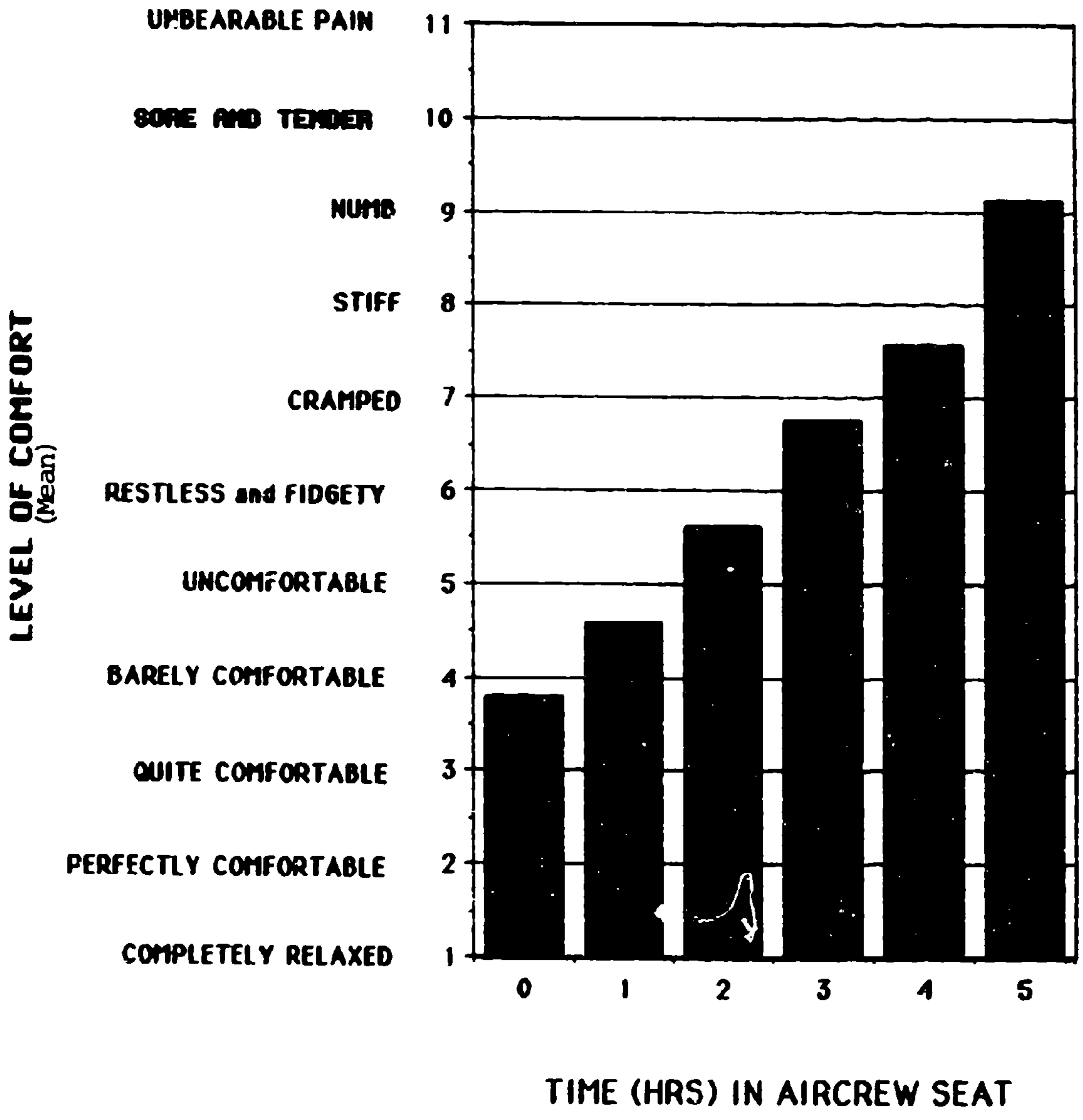


Figure 7. Results of General Comfort Rating.
(Presented Using Means).

AIRCREW SEAT STUDY
MODIFIED BODY PART DISCOMFORT FORM

INSTRUCTIONS: Please mark one "X" on each horizontal line. Place your "X" at a place on the line which describes how that part of your body feels now. If you do not feel any discomfort or pain in a particular body part, leave that line blank. The left hand side of the solid line corresponds to just noticeable pain/discomfort, the middle of the line to medium or moderate pain/discomfort, and the far right end of the line to intolerable or severe pain/discomfort. Remember that you may put your "X" anywhere on the solid lines. For example, if you feel a degree of discomfort somewhere between just noticeable pain/discomfort and moderate pain/discomfort you should mark your "X" somewhere on the line between these two points.

INITIALS ____________
DURATION OF
EXPOSURE /FLIGHT ______________

DATE ________________

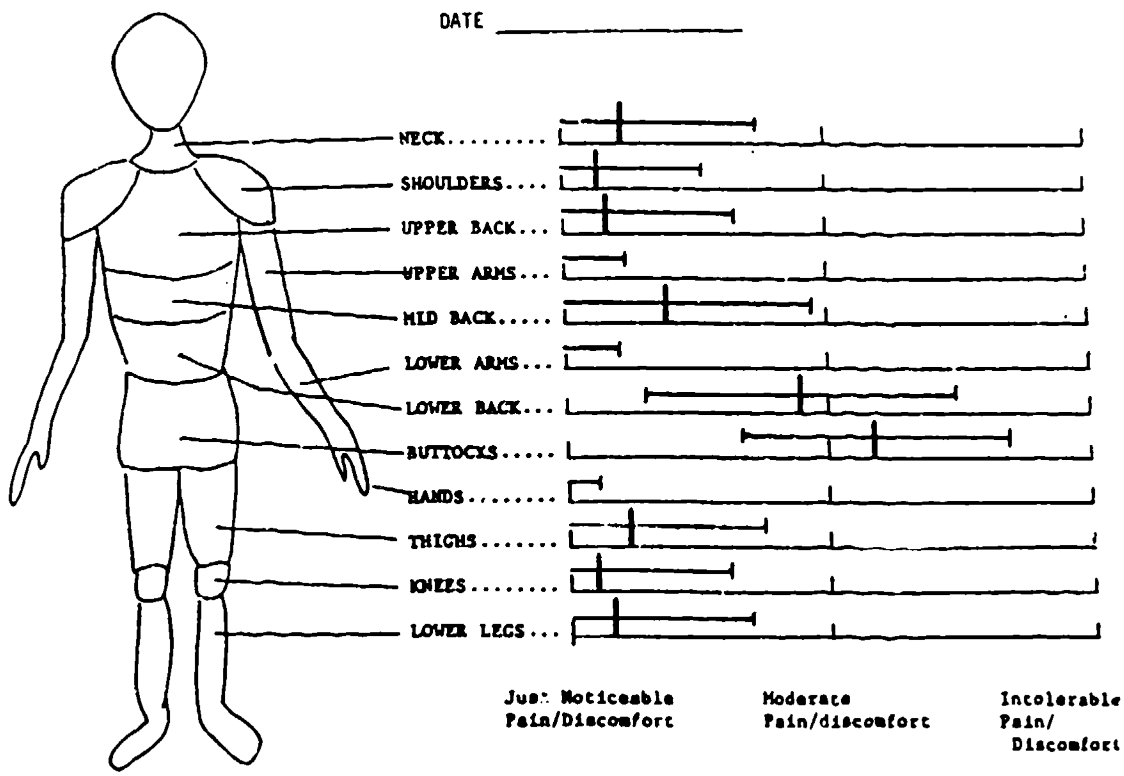


Figure 8. Results of Body Part Discomfort Survey. (Presented Using Means and Standard Deviations).

seat pan design, seat cushion material, back support design and back support cushion material. The necessity of having a well designed aircrew seat to optimize performance and comfort is paramount, yet the major interfaces between man and seat (ie. seat pan, seat cushion, backseat, back cushion) available on the C-130 aircrew seats do not provide the long duration mission support required by aircrew members.

Because the current aircrew seat was structurally acceptable, it was decided that the aircrew seat would be modified/redesigned to accommodate a seat pan and backrest individually designed for the long duration mission. In addition, new seat pan and backrest cushions would be designed and developed for this prototype seat, incorporating state-of-the-art technology in medium density, open-celled polyurethane foam.

DEVELOPING AIRCREW SEAT DESIGN GUIDELINES

Design guidelines were developed prior to actual modification of the aircrew seat. The guidelines were established by:

1. Reviewing previous design guidelines for the task to be performed and determining the strengths and weaknesses of the guidelines.

2. Presenting and defending the rationale behind the new guidelines to help eliminate the shortcomings of the previous design guidelines.

Proposing and Defending New Guidelines

In the realm of flying, especially in military aircraft, the pilot should be comfortable in his surroundings, yet alert and able to make split-second decisions and movements. The piece of equipment in the cockpit which typically determined whether or not the pilot will be comfortable is the aircrew seat. The aircrew seat, therefore, must be designed such that it is comfortable to the pilot and thus reduces his physical fatigue while enabling top (peak) performance. The following paragraphs propose guidelines and rationale to design the aircraft aircrew seat for the pilot, instead of satisfying a basic military standard. These guidelines were developed by interviewing C-130 aircrew members and through the author's past flying experience.

Since the pilot is required to keep his feet on the rudder pedals during flying operations and the seat adjustments (control assemblies which adjusts the aircrew seat) are within easy reach of the pilot, they should not be changed.

The seat bucket, which is imperative to the structural integrity of the aircrew seat, should be maintained. However, a seat pan and seat cushion should be designed which provides more surface area to help distribute the weight of the pilot more uniformly over the buttock-thigh contact surface area. This will help improve blood circulation in the buttocks and lower extremities and reduce the pressure on the ischial tuberosities. Confor foam should be used as the cushion material due to its ability to conform to an individual's contours while providing resiliency, impact absorption and a slow rate of return from deflection. The seat pan design concept should incorporate a saddle and cultivator seat with leg troughs for support which will counter the ejection force experienced in a aircrew seat (Congleton et al., 1985). Additionally, the seat pan underside must be designed to fit into the existing seat bucket and be easily installed or removed by the crew chief or other maintenance personnel.

The armrests should not be changed. Any major modifications to the armrests could impede the pilot's ability to ingress or egress the seat, and this would make it a safety-of-flight issue.

The backrest should be modified by designing a secondary backrest insert which attaches directly to the

original. This insert should incorporate a square back to provide support to the shoulder region. The corresponding back cushion, which fits within the insert, should be made of a polyurethane foam and should be the same dimensions as the insert. The insert and cushion should have the ability to be rapidly installed or replaced, while still meeting crash-worthiness standards. Between the cushion and insert, a lumbar air bladder should be installed so that the aircrew member can adjust the lumbar support, prior to takeoff, to meet his own individual needs. During flight, the aircrew member could adjust the level of lumbar support either by pumping air into the system or allowing it to escape. The material used to cover the cushion and bladder should be fire resistant and easily removed and cleaned.

The following two experiments will help demonstrate the usefulness of the modified aircrew seat in increasing aircrew comfort and performance.

EXPERIMENT NO. 1: DYNAMIC VIBRATION EXPOSURE

Experiment No. 1 was specifically designed to collect subjective, physiological and human performance data in a situation that closely approximated the actual flying environment, while contrasting three different aircrew seats. Because it satisfied this condition and

was available, the SIXMODE Vibration Facility at Wright-Patterson Air Force Base (AFB) was used to provide pseudorandom vibrations of the frequency and intensity which one would experience while flying a Lockheed C-130 Hercules transport aircraft. The actual design of the experiment was influenced by the following criteria:

1. The vibration exposure was limited to one hour and thirty minutes due to the mental fatigue (boredom) associated with the human performance tests and the m ate discomfort associated with sitting for hour and thirty minutes while being exposed to vibration similar to a C-130 in flight. Additionally, cost and facility availability considerations were limiting factors.
2. The human performance tasks had to provide feedback to the operators, after each run, to provide them with a feel for how they were performing.
3. The human performance tasks were measurable either with respect to number of correct/incorrect answers, boundary hits or reaction time data.
4. The ease of installing/removing aircrew seats following each vibration exposure.

5. The amount of time a test participant was allowed to experience a particular vibration exposure and the duration of time thereafter where he was unable to participate.

Human Performance Measures

The selection of the particular human performance measures was based upon established test validity, availability of a standardized set of tasks and relevance to military personnel performance (Englund, Reeves, Shingledecker, Thorne, Wilson and Hegge, 1985). The four measures, Critical Instability Tracking Task, Memory Search Task, Pattern Comparison Task and Combined Memory Search - Tracking Task, were all developed to provide an instrument to measure human performance that was both practical and firmly based in current theoretical models of perceptual motor and cognitive behavior. These individual tasks are used to selectively place demands upon the resources of the operator (Shingledecker, 1984).

Critical Instability Tracking Task. This task was similar to the task developed by Jex, McDonnell and Phatak (1966). In the task, test participants viewed a video screen displaying a tracking symbol. An inverted triangle (cursor) moved horizontally left and right from

the center, marked by a stationary triangle. The participant attempted to maintain the cursor in the center position by manipulating a single axis joystick. The instability of the system was activated by the subject's movement of the joystick along with an initial error whose value was predetermined by the experimenter. While the subject attempted to maintain the center position, the error (degrees off center) of the cursor was recorded, transformed, and then added back into the system to increase the movement of the cursor. If a boundary was hit, the cursor would automatically reset to the center position and after a predetermined amount of time (1 sec), the task resumed. The task continued for the predetermined task duration of twenty minutes (Critical Instability Tracking Task, 1985).

Memory Search Task. In the Memory Search Task, the test participant was given a small number of probes (letters/digits) to memorize. These probes were referred to as the positive set. The subject was then shown a series of probes that did or did not belong to the positive set. Those probes not in the positive set were referred to as the negative set. When a probe was presented, the subject had to decide, as quickly as possible, if it belonged to the previously memorized positive set. If the probe belonged to the positive set,

the subject pressed the positive response key. If the probe did not belong to the positive set, the subject pressed the negative response key. Subjects were instructed to respond quickly but accurately. Data was collected by measuring the speed (in milliseconds) and the accuracy of responses (Memory Search Task, 1985).

Pattern Comparison Task. In this task, two generated patterns were presented on the screen simultaneously. The subject was to compare the two patterns, determine if they were the same or different, and enter a response as rapidly but accurately as possible. If the patterns were the same, the participant pressed the "same" response key. If the patterns were not the same, the subject pressed the "different" response key. Data was collected by measuring the response time and the number of correct and incorrect responses (Pattern Comparison Task, 1985).

Combined Memory Search - Tracking Task. This dual task was a combination of the Memory Search Task (visual fixed set) and the Critical Instability Tracking Task. The test participant initiated the start of the task after viewing the positive set. The memory search stimulus was presented just above the tracking symbol, which was centered on the screen. Although the combined

task began at the same time, the memory search stimulus initally appeared a few msec after the appearance of the tracking symbol due to the time defined for the interstimulus intervals. The combined task continued until the last probe was presented (Combined Memory Search-Tracking Task, 1985).

Subjective Surveys

Aircrew General Comfort Rating. To contrast the various aircrew seat treatments utilized in the study, several subjective surveys were employed. The General Comfort Rating (Figure 9), developed by Shackel et al. (1969), was utilized extensively to monitor comfort during the entire vibration exposure period. At predetermined (forty-five minute) intervals during the experiment, participants were asked to indicate the level of comfort they were currently experiencing. This information was collected to provide real time comfort dat .

Aircrew Body Part Discomfort Survey. The Body Part Discomfort Survey used in the experiment was initially modified by Congleton (1983), and then by this experimenter (Figure 10), to allow finer discrimination of body part discomfort/pain than was available on Drury

AIRCREW SEAT STUDY
GENERAL COMFORT RATING

Instructions: Please mark only one "X" on the vertical line. Place the "X" at a place on the vertical line which corresponds to how comfortable you feel in the chair you are now sitting in.

Please rate the chair you are sitting in on your feelings now.

- I feel completely relaxed.
- I feel perfectly comfortable.
- I feel quite comfortable.
- I feel barely comfortable.
- I feel uncomfortable.
- I feel restless and fidgety.
- I feel cramped.
- I feel stiff.
- I feel numb (on pins and needles).
- I feel sore and tender.
- I feel unbearable pain.

INITIALS ____________

DATE ______________

Figure 9. Aircrew General Comfort Rating Form.

AIRCREW BODY PART DISCOMFORT FORM

INSTRUCTIONS: Please mark an "X" on each horizontal line where you feel pain or discomfort. Place your "X" at a place on the line which describes how that part of your body feels now. If you do not feel any discomfort or pain in a particular body part, leave that line blank. The left hand side of the solid line corresponds to just noticeable pain/discomfort, the middle of the line to medium or moderate pain/discomfort, and the far right end of the line to intolerable or severe pain/discomfort. Remember that you may put your "X" anywhere on the solid lines. For example if you feel a degree of discomfort somewhere between just noticeable pain/discomfort and moderate pain/discomfort you should mark your "X" somewhere on the line between these two points.

INITIALS ______________

DURATION OF
EXPOSURE/FLIGHT __________

TRIAL # ________________

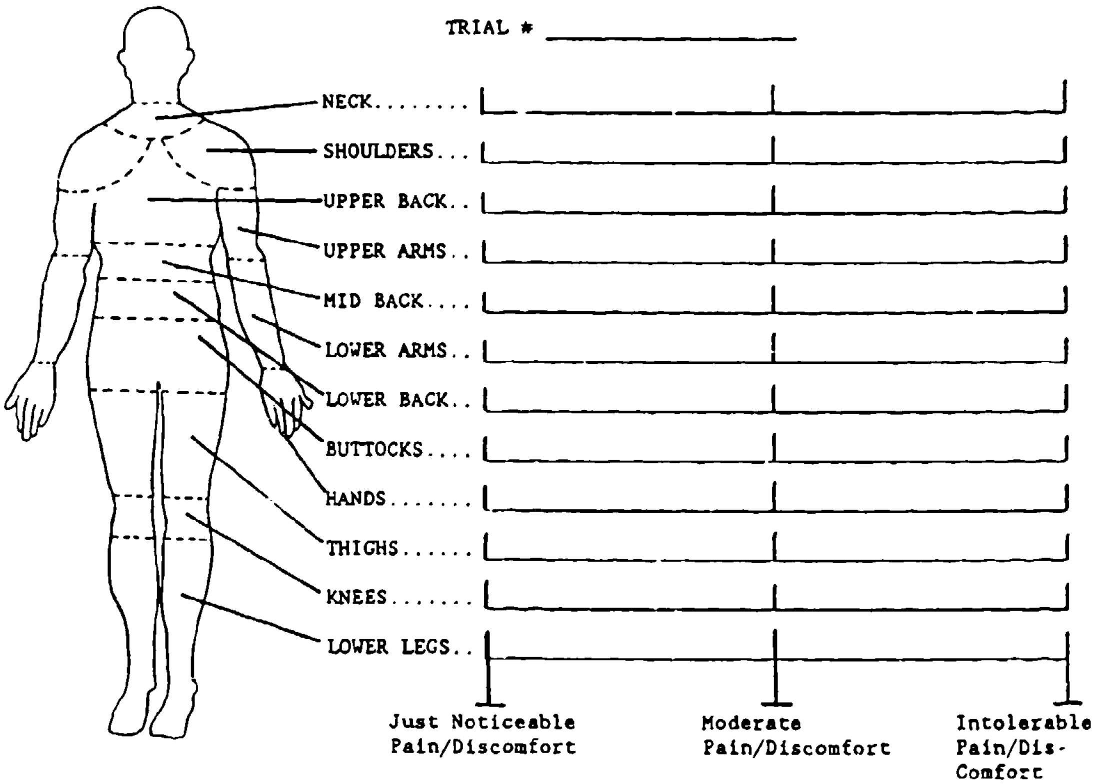


Figure 10. Aircrew Body Part Discomfort Form.

and Coury's (1982) Body Part Discomfort form which incorporated a five point scale. Instead of selecting a number between one and five to represent levels of discomfort, the test participants were required to place an 'X' anywhere along the continuum to coincide with the degree or level of discomfort or pain they were experiencing in each respective body part at the time the survey was implemented. Each particular body part had a 10 cm line or continuum on which the participants could place their 'X'. To determine discomfort/pain levels, the position of the 'X' was measured, in centimeters, from the left-hand side to the X's intersection with the line. The survey was scaled such that the far left measure was equivalent to one (1) and the far right point was eleven (11), with a zero (0) value being recorded if the respondent indicated no noticeable pain/discomfort. By employing this modified form, the three aircrew seat treatments could be statistically analyzed to test for significant differences.

Aircrew Seat Feature Checklist. In order to identify those features which were acceptable, desirable or undesirable with the current aircrew seats, a modified version of the Chair Feature Checklist was utilized. This version, called the Aircrew Seat Feature Checklist (Figure 11), included changes which were unique to

AIRCREW SEAT FEATURE CHECKLIST

INSTRUCTIONS: Below is a list of seat features which contribute to comfort. On the right hand side of the page, opposite each feature, are three brief phrases descriptive of the feature. Mark on the line with an "X" at a point which describes the opinion you have of that feature. The endpoints of the lines are the extreme cases. Be sure to put only one "X" on each and every line.

INITIALS ______

DATE __________

TRIAL #________

AIRCREW SEAT TYPE ______________

*PLEASE WRITE ANY COMMENTS (LIKES OR DISLIKES) CONCERNING THE SEAT ON THE BACK OF THIS FORM

SEAT:

		too low / too short / etc.	correct	too high
1.	Seat height adjustability above the flight deck	too low	correct	too high
2.	Seat length	too short	correct	too long
3.	Seat width	too narrow	correct	too wide
4.	Slope of seat	slopes too far towards back	correct	slopes too far towards front
5.	Shape of seat	poor fit	adequate	fits well
6.	Padding in seat	needs more	correct	needs less

Figure 11. Aircrew Seat Feature Checklist.

BACKREST:

1.	Adjustability of backrest	too low	correct	too high
2.	Shape of backrest	poor fit	adequate	fits well
3.	Curvature of backrest	too flat	correct	too curved
4.	Lumbar support	needs more	correct	needs less
5.	Padding in backrest	needs more	correct	needs less

OVERALL:

1.	Opinion of this Aircrew Seat	dislike	indifferent	like very much

Figure 11. (Continued).

aircrew seating and thus provided a better description of the aircrew seat. However, the mechanics were essentially the same as employed by Congleton (1983). Respondents were instructed to mark an "X" at a point along the line which corresponded with the feelings of the aircrew member. It was felt that this more accurately measured their opinion than circling a point, as was done by Drury and Coury (1982). These checklists were filled out as part of the third and final set of data collected during each vibration exposure, thus allowing the test participants ample time to become familiar with the aircrew seat they were rating.

Post Test. The Post Test questionnaire (Figure 12) was developed as a means of determining which aircrew seat subjects preferred most after having been exposed to all three types. The subjects were merely required to rank each seat, from the one they liked the most to the one they liked least. Since this questionnaire was filled out after each subject had experienced each aircrew seat, it was filled out only once at the completion of the testing.

AIRCREW SEAT POST TEST

PREFERENCE QUESTIONNAIRE

INSTRUCTIONS:

Please rank the aircrew seats which you experienced in the experiment from one (1) to three (3). A one (1) would correspond with the aircrew seat you most preferred, whereas a three (3) would be the seat which you least preferred. The following are the aircrew seats which you are to rate:

a. C-130 Aircrew Seat

b. Modified C-130 (Version #1) Aircrew Seat

c. Modified C-130 (Version #2) Aircrew Seat

Please fill in the blanks with your preferences.

1. ______________________________(most preferred)

2. ______________________________

3. ______________________________(least preferred)

COMMENTS:

In the following space please feel free to make any comments or suggestions concerning any of the aircrew seats you experienced. Thank you for being a participant in this experiment.

Figure 12. Post Test Questionnaire.

Test Participants

All 12 subjects participating in the vibration testing were right-handed male members of the AAMRL Impact and Vibration Panel which was composed of approximately 25 volunteer active duty Air Force members. All of the participants were unfamiliar with the C-130A seat used in the experiment. These individuals qualified for the panel only after passing an intensive medical evaluation (Hearon and Raddin, 1981). This evaluation consisted of a physical examination performed by an AAMRL flight surgeon, and included visual acuity, audiometry, blood pressure determination, routine blood work and urinalysis, standard 12-lead EKG and chest X-rays. Refraction was not typically performed. Additional tests included pulmonary function tests, electroencephalogram, treadmill exercise stress test and complete skull and spine x-rays which were required only upon initial evaluation and termination of panel participation. These x-rays were reviewed by the panel monitor in consultation with a radiologist (and an Orthopedic Surgeon, as necessary). Annual physical exams were required with periodic repetition of relevant additional testing. The complete battery of tests was not repeated until the volunteer terminated his panel participation.

Before participation in a particular experiment, subjects were briefed on the purpose of the project, the nature of the vibration they would experience, and any anticipated discomfort and risks. If they chose to participate, they signed a witnessed consent form (Appendix A) which attested to the fact that a detailed briefing was received and summarized its content. The subjects were eligible for acceleration stress incentive pay per the DOD Military Pay and Allowances Entitlement Manual during the months in which they participated.

Their primary duties did not involve participation as subjects. They were strictly volunteers for the investigations and performed normal duty within various Wright-Patterson organizations. There was no special technical qualification for the subjects. All subjects underwent an intensive medical screening evaluation as mentioned previously, prior to their acceptance as panel members.

Twelve male subjects were used to ensure an adequate sample size for statistical analysis of the performance data. However, 14 or 15 subjects were selected to ensure a sufficient margin should difficulties occur in subject availability. All subjects approximated the age of the pilot population.

The subjects were each fitted with a Nomex flight suit, flight boots and a headset. The headset was part of a two-way intercom system enabling the subjects to communicate with the test administrator, SIXMODE operator, and subject monitor. A test session required approximately 2 hours of the subject's time. Exposure to vibration was limited to approximately 1 hour and 30 minutes. One session was required to collect data for each of the three treatments. Test sessions were typically scheduled twice per day. A subject who had participated in an impact test was not exposed to the vibration test for at least 24 hours.

Variables

The dependent variables in this experiment were:

1. Critical Instability Tracking Task data.
   a) The root mean square (RMS) offset from the center position.
   b) The number of boundaries hits.

2. Memory Search Task data.
   a) The mean reaction time for correct responses to probes.
   b) The mean reaction time for both correct and incorrect responces to probes.

c) Number of probes correctly recognized.

d) Number of probes incorrectly recognized.

3. Pattern Comparison Task data.

a) The mean reaction time for correct pattern identification.

b) The mean reaction time for both correct and incorrect pattern identification.

c) Number of patterns incorrectly identified.

d) Number of patterns correctly identified.

4. Combined Memory Search - Tracking Task data.

a) The mean reaction time for correct responses to probes.

b) The mean reaction time for both correct and incorrect responses to probes.

c) Number of probes correctly identified.

d) Number of probes incorrectly identified.

e) Number of boundaries hits.

f) The RMS offset from the center position.

5. Subjective Survey data.

a) Aircrew General Comfort Rating as outlined in Figure 9.

b) Aircrew Body Part Discomfort Survey as illustrated and described in Figure 10.

c) Aircrew Seat Feature Checklist as presented and described in Figure 11.

d) Post Test questionnaire as outlined in Figure 12.

6. Spinal Creep Measurements

a) Area difference between the pre- and post-test spinal contour measurements from C-7 to S-1.

b) Length difference (along spinal curvature) between pre- and post C-7 to S-1 measurements.

c) Height difference (pre- and post-test measurements of the straight line distance from C-7 to S-1).

The independent variables in this experiment were:

1. The current AMI C-130 aircrew seat.
2. Modified (MOD-REG) C-130 aircrew seat with regular foam.
3. Modified (MOD-CONF) C-130 aircrew seat with Confor foam.

The constant values in this experiment were:

1. Duration of vibration exposure.
2. Angle of backrest.
3. Seat position.

4. Seat height equivalent for all participants
5. Control stick response box and CRT placement equivalent for all participants.
6. Pseudorandom vibration.
7. Time of day.

Facilities

The SIXMODE Vibration Facility, located in Bldg. 824. Wright-Patterson AFB, OH, was required to produce pseudorandom vibration stimuli for Experiment No. 1 (Figures 13 & 14). The SIXMODE Vibration Table produced the single-axis vibration spectrum at the payload required for the experiment (Figure 15). Figure 16 displays the vibration table after the aircraft cockpit had been installed on the platform. Figure 17 presents the control room for the SIXMODE and all of the associated instrumentation. Through the control room window the aircraft cab can be seen, ensuring that the operator has direct visual contact with the subject and the vibration table. For more details concerning the SIXMODE, refer to Appendix B.

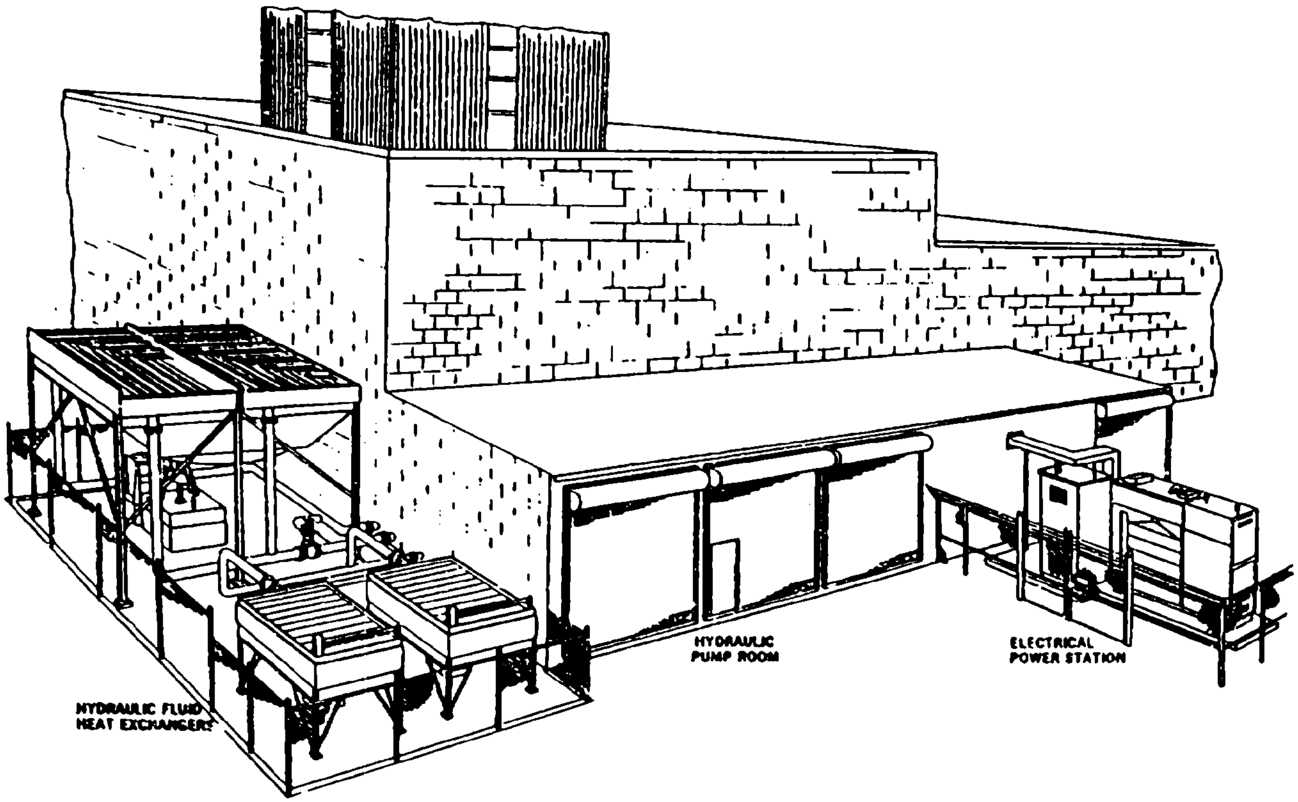


Figure 13. S.AMODE Facility Exterior Equipment. (Adapted from Muhic, 1980).

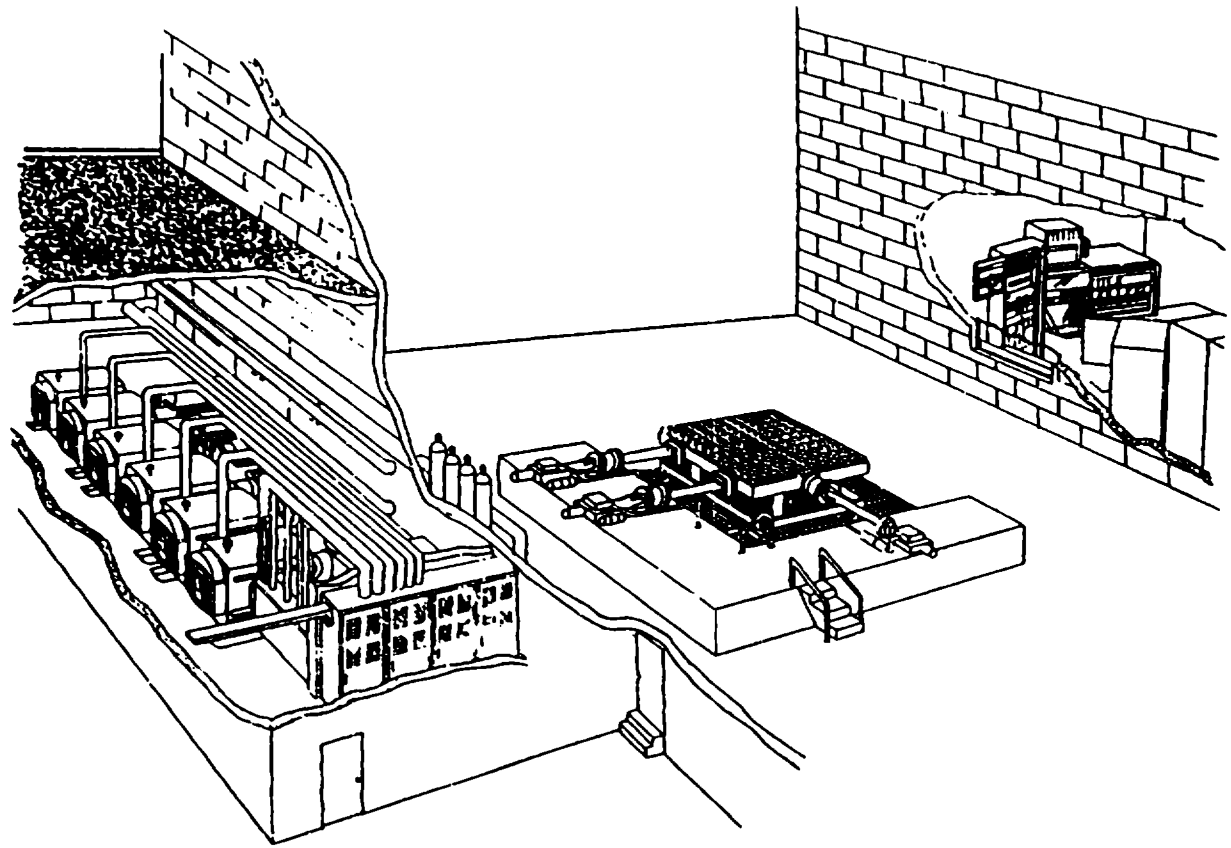


Figure 14. SIXMODE Vibration Facility. (Adapted from Muhic, 1980).

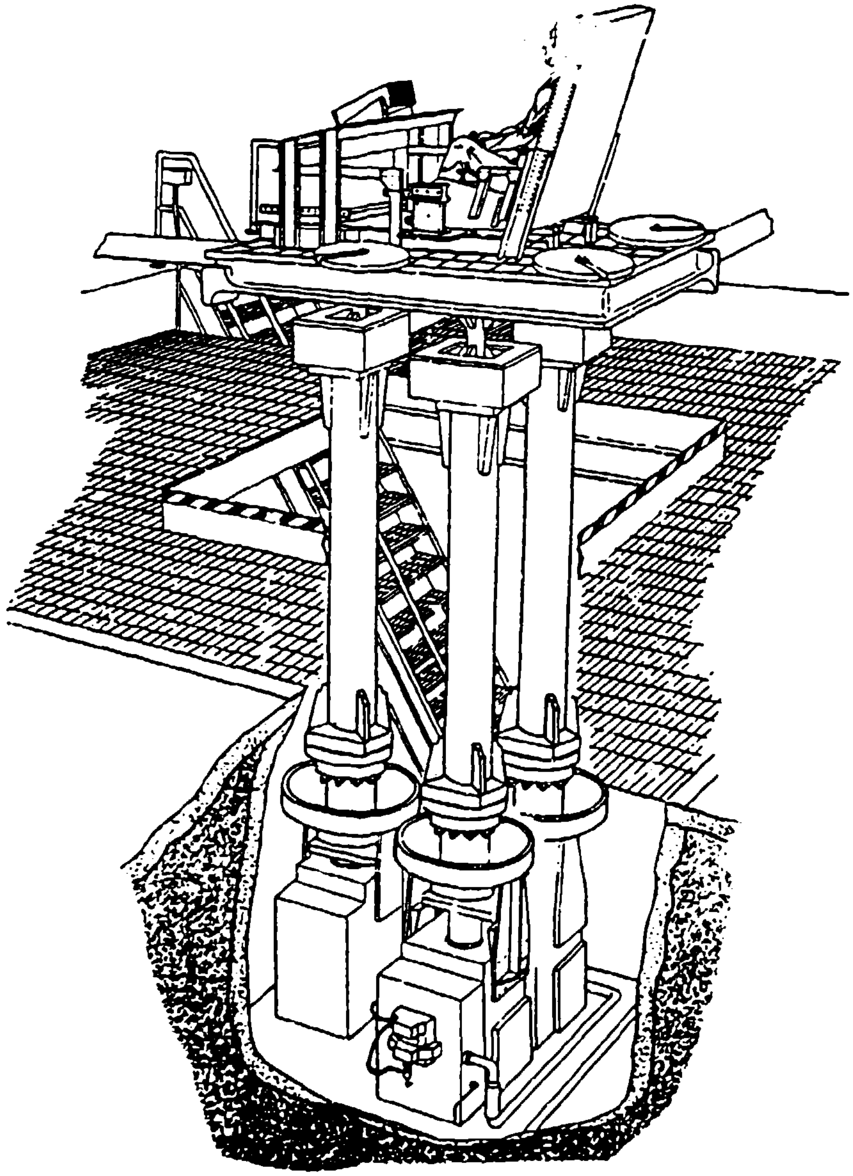


Figure 15. SIXMODE Vibration Table. (Adapted from Muhic, 1980).

Figure 16. SIXMODE with Aircraft Cockpit.

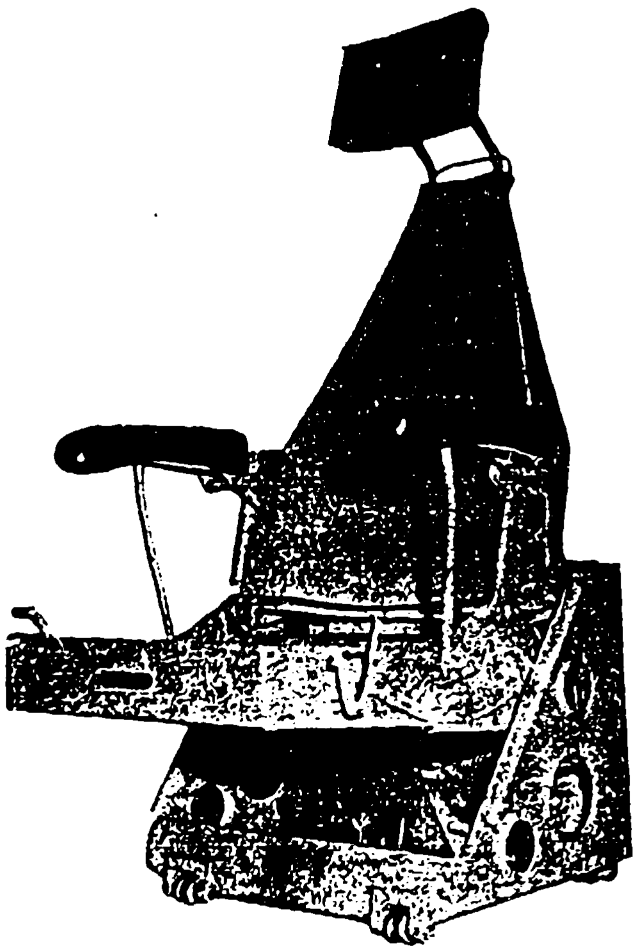
Figure 17. SIXMODE Control Room.

Equipment

Before any testing was conducted, all subjects were measured with anthropometric measuring devices to determine their relative percentiles, based upon the 1967 USAF Pilot data base. Weight measurements of the test participants were obtained with the use of a scale. Each participant, prior to vibration exposure, was required to wear underwear, undershirt, socks, a USAF Nomex flight suit, USAF flight boots and a transport aircraft headset.

Three C-130 pilot/co-pilot seats were utilized in the experiment: the current AMI C-130 aircrew seat, the modified (MOD-REG) C-130 aircrew seat and the modified (MOD-CONF) C-130 aircrew seat.

AMI C-130 seat. The current AMI C-130 aircrew seat, shown in Figure 18, was structurally divided into three major sub-assemblies consisting of the triangular seat back, the bucket assembly and the base assembly. Within the seat bucket assembly resided a seat cushion which consisted of a 40.64 cm (15 7/8 inch) by 35.52 cm (13 7/8 inch) by 11.20 cm (4 3/8 inch) piece of molded styrofoam with a 43.20 cm (16 7/8 inch) by 35.52 cm (13 7/8 inch) by 5.76 cm (2 1/4 inch) to 7.04 cm (2 3/4 inch) rounded polyurethane foam pad on top (Figure 19). This entire cushion was enclosed by a bright orange, fire resistant



Model 589

Figure 18. AMI Aircrew Seat.
(Adapted from Department of Defense, 1972).

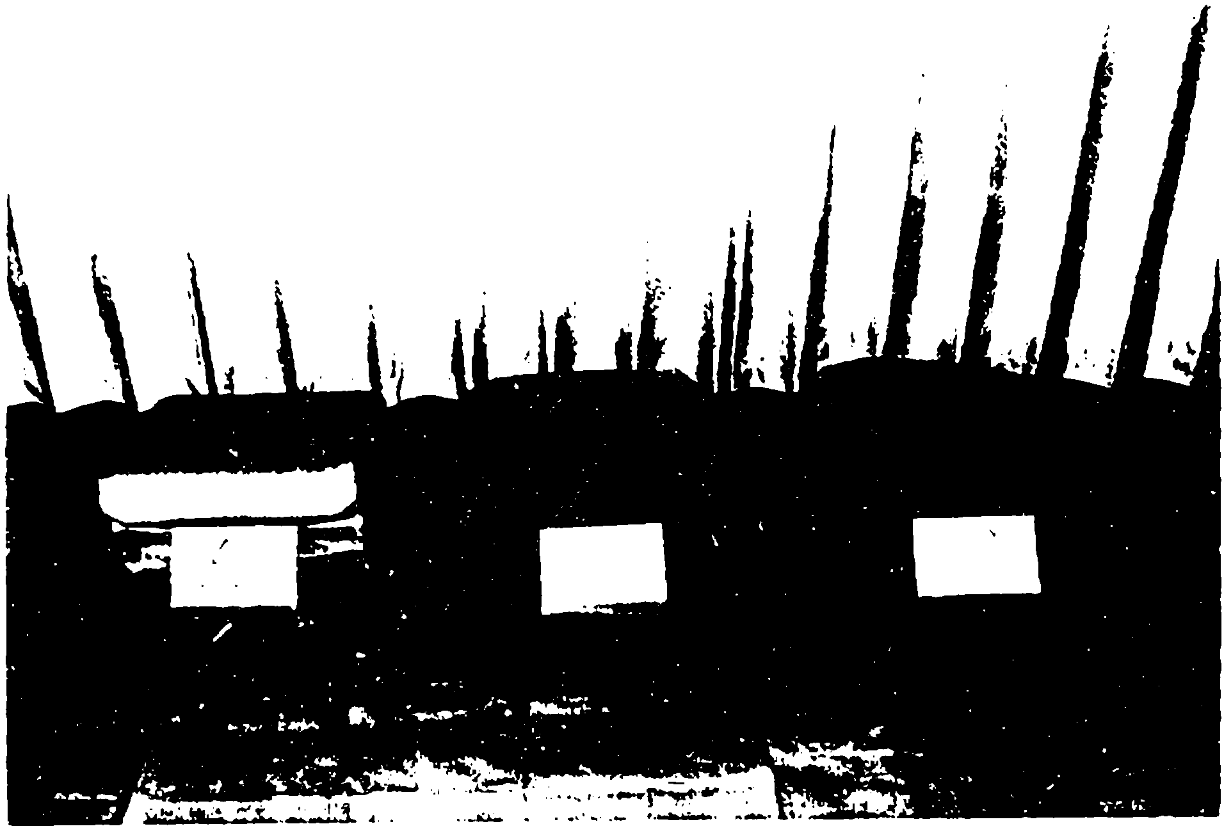


Figure 19. Aircrew Seat Pans with Cushions. (A = Current AMI Seat Pan and Padding, B = MOD-REG Seat Pan and Padding and C = MOD-CONF Seat Pan and Padding).

cover which could be easily removed and cleaned. The back cushion was of the same foam material as the top section of the seat cushion and was triangular in shape to fit the back rest (Figure 20). This back cushion was also enclosed by the orange, fire resistant material.

MOD-REG seat. The modified (MOD-REG) C-130 aircrew seat, shown in Figure 21, was structurally the same as the current AMI C-130 aircrew seat with the exception that the seat pan had been redesigned. By incorporating a contoured seat pan, the length of the seat pan, as well as the width, was increased. This allowed more contact surface area for the buttock-thigh region and allowed the individual to sit in a more neutral body posture. Also, by using a new polyurethane foam which provided more resiliency, impact absorption and a slow rate of return from deflection, the pilot's weight was more evenly distributed over this area. This not only improved blood circulation in the buttocks and lower extremities, but also reduced ischial tuberosity pressure. Additionally, a new backrest insert was designed to support the shoulders and provide a self-pumped bladder type lumbar support system which was adjustable to the user's desires and specifications (Figure 20). This was all covered by a polyurethane foam back cushion which provided the necessary padding for the backrest.

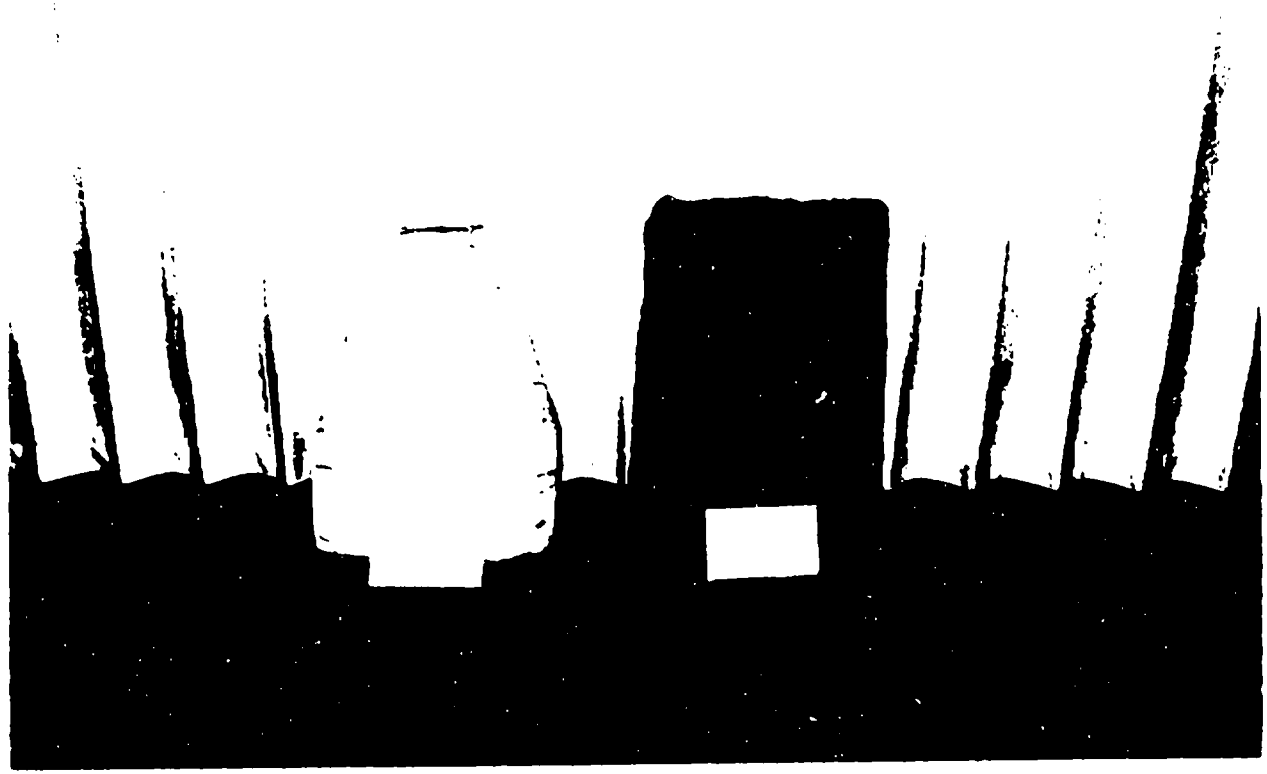


Figure 20. Aircrew Seat Backrest Cushions. (1 = Current Aircrew Seat Backrest, 2 = MOD-REG and MOD-CONF Backrest Cushion).

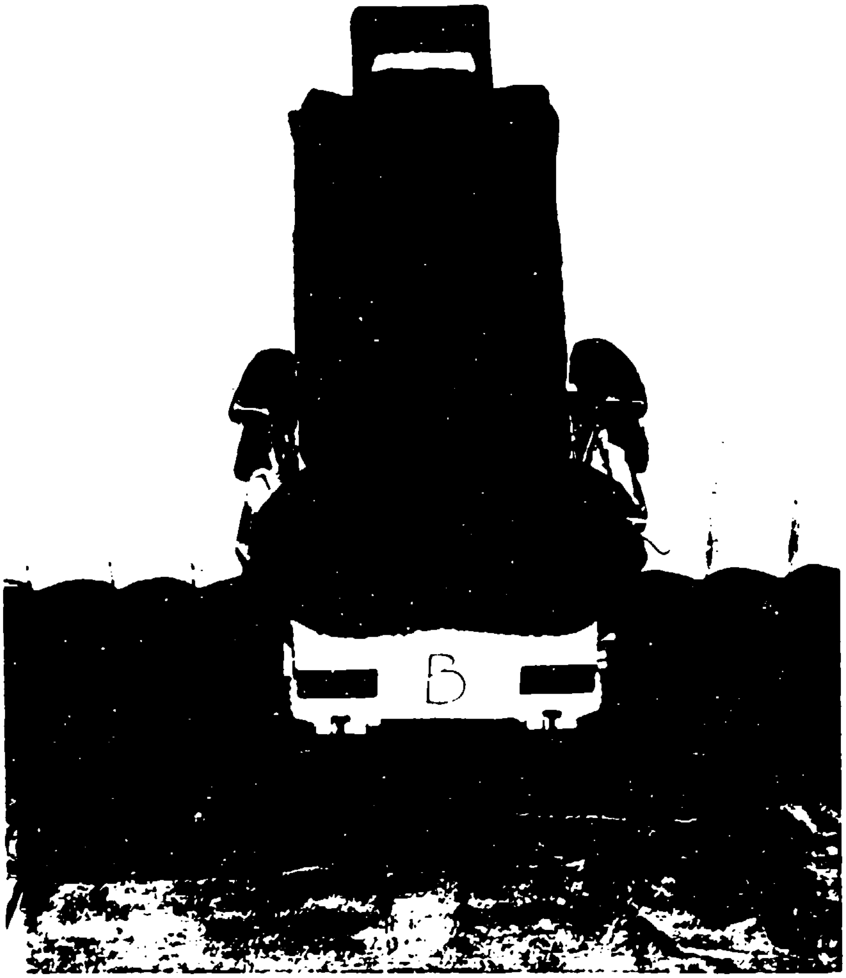


Figure 21. MOD-REG Aircrew Seat.

MOD-CONF seat. The modified (MOD-CONF) C-130 aircrew seat was structurally the same as the current AMI seat, however the seat pan and backrest reflected the changes made for the MOD-REG aircrew seat (Figure 22). This seat pan incorporated the use of Confor foam, which was a new, high technology foam which did not collapse under g-loading forces and additionally had the property of distributing the weight of the upper body evenly over the buttocks and thigh contact surface area. The same backrest and backrest cushion, as was described for the MOD-REG aircrew seat, were used.

Spinal contour measuring device. Spinal creep measurement was performed using the spinal contour measuring device located in Bldg. 824, Wright-Patterson AFB (Figure 23). This device was essentially comprised of a series of steel bars lined up on top of each other from a height of three feet above the floor to a height of six feet (approx.). With steel bars situated in such a manner, an impression of the individual's spinal column was made by having the individual back up to the rods, aligning the spine over the rods and then contouring the rods to match the curvature of the spinal column (Figure 24). This imprint was then preserved by using photosensitive paper (Figure 25). The pre-spinal column measurement was digitized and later compared to the

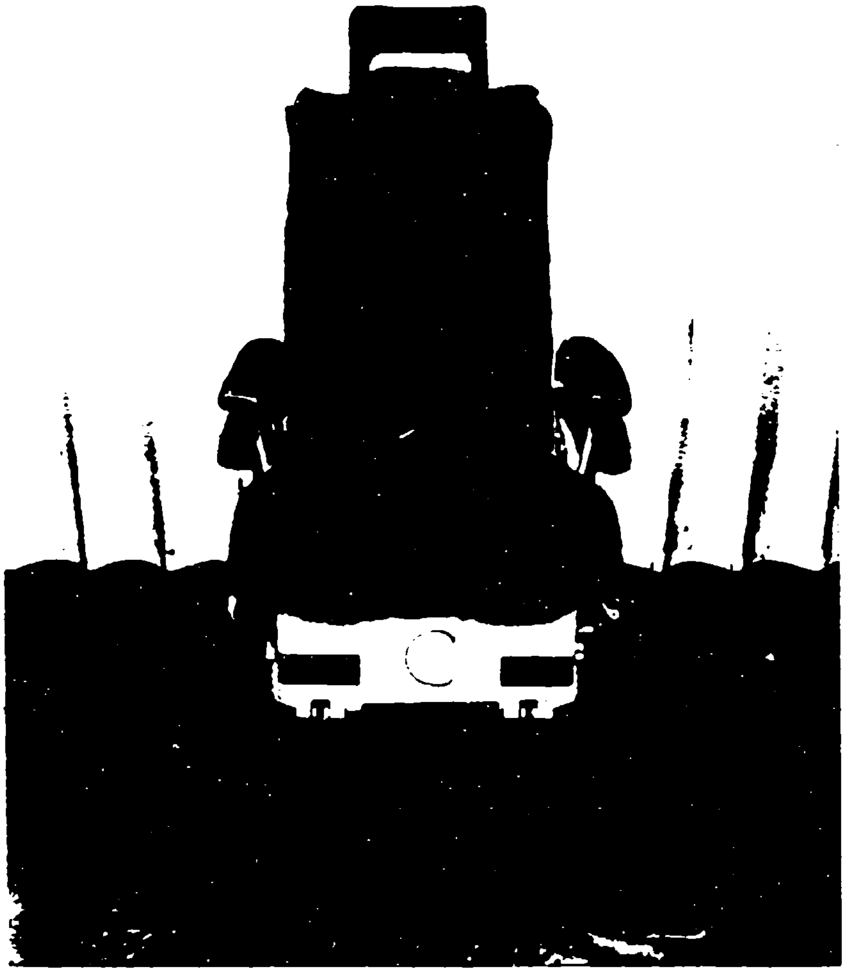


Figure 22. MOD-CONF Aircrew Seat.

Figure 23. Spinal Contour Measuring Device.

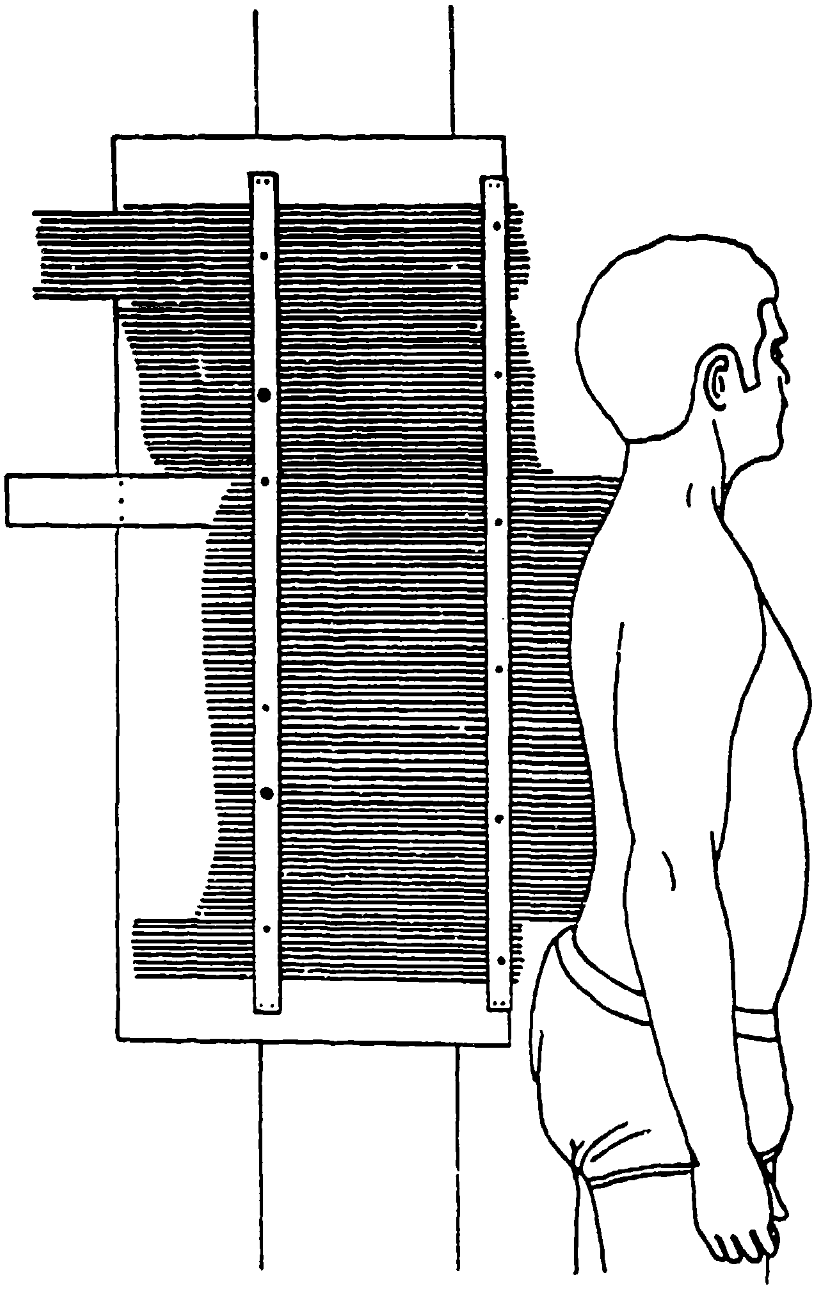


Figure 24. Spinal Creep Measurement.

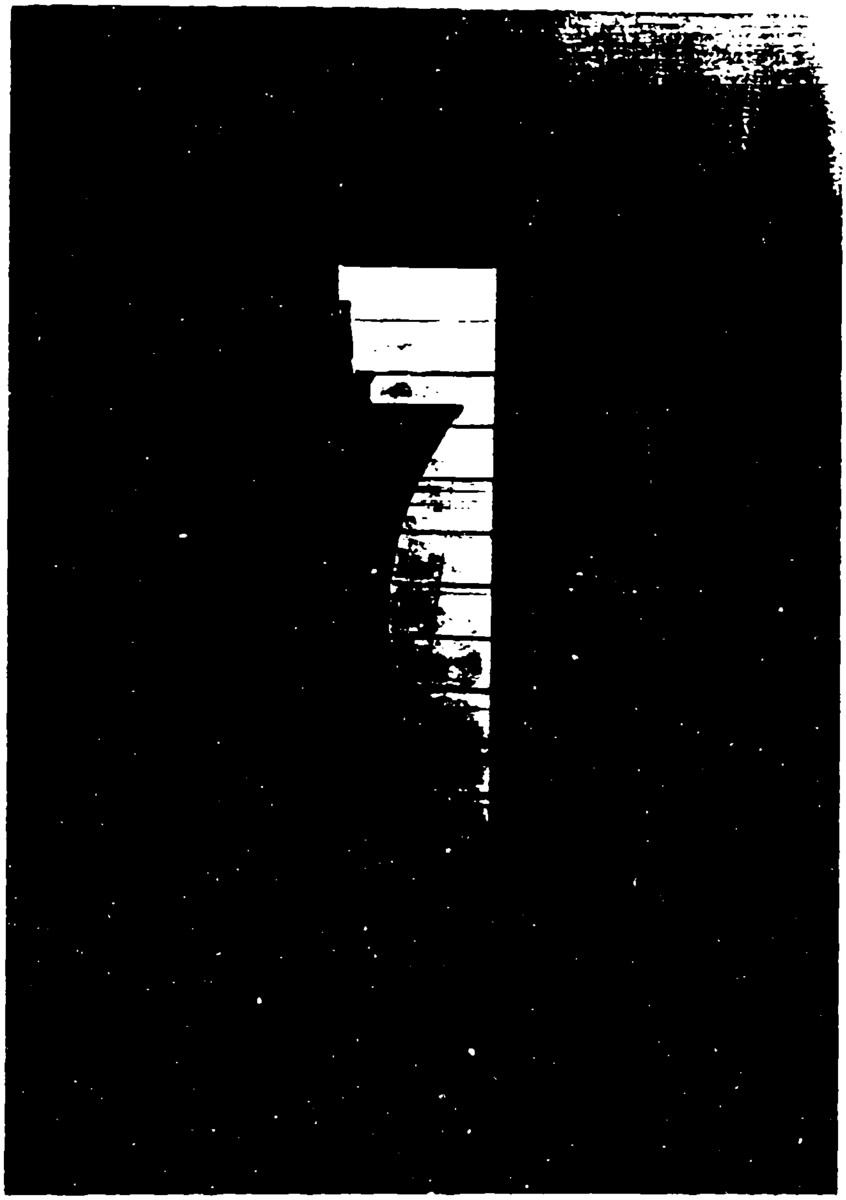


Figure 25. Imprint of Spinal Measurement.

digitized measurement taken after the completion of the experimental test. This was done to determine the change in the spinal area, curvature and height (Kazarian, 1975).

Workload assessment equipment. Human performance measurement was accomplished using Systems Research Laboratory's (SRL) prototype Workload Assessment Device (WAD) field unit (Figure 26) and data download system (Figure 27). Together, the two systems were used as a Performance Assessment Test Battery Computer. The combined WAD system was comprised of two 5 1/4 inch floppy disc drives, two 8 inch floppy disc drives, a WYSE keyboard, a G.R. Electronics Pocket Terminal type 14, a PGS SR-12 color monitor, a WYSE amber monitor and an Epson 800 printer. The control stick box, with two identical sets of response buttons, and an EGA color monitor were mounted inside the cockpit on a custom built rack (Figure 28). A video camera and recorder were selectively used to document activity at given times during the testing.

Procedure

Practice session. The test participants were instructed to report to AAMRL/BBD Bicdynamic Effects

Figure 26. WAD Field Unit.

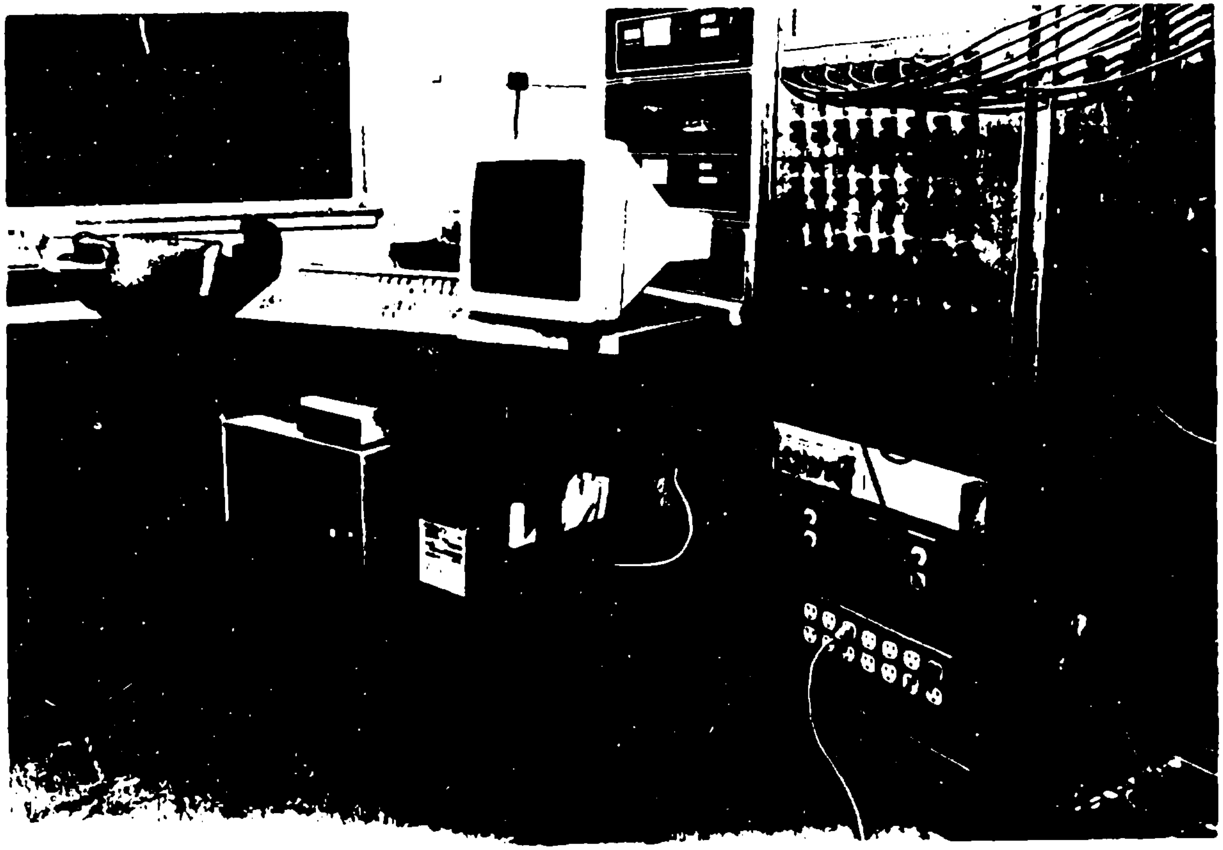


Figure 27. WAD Data Download System.

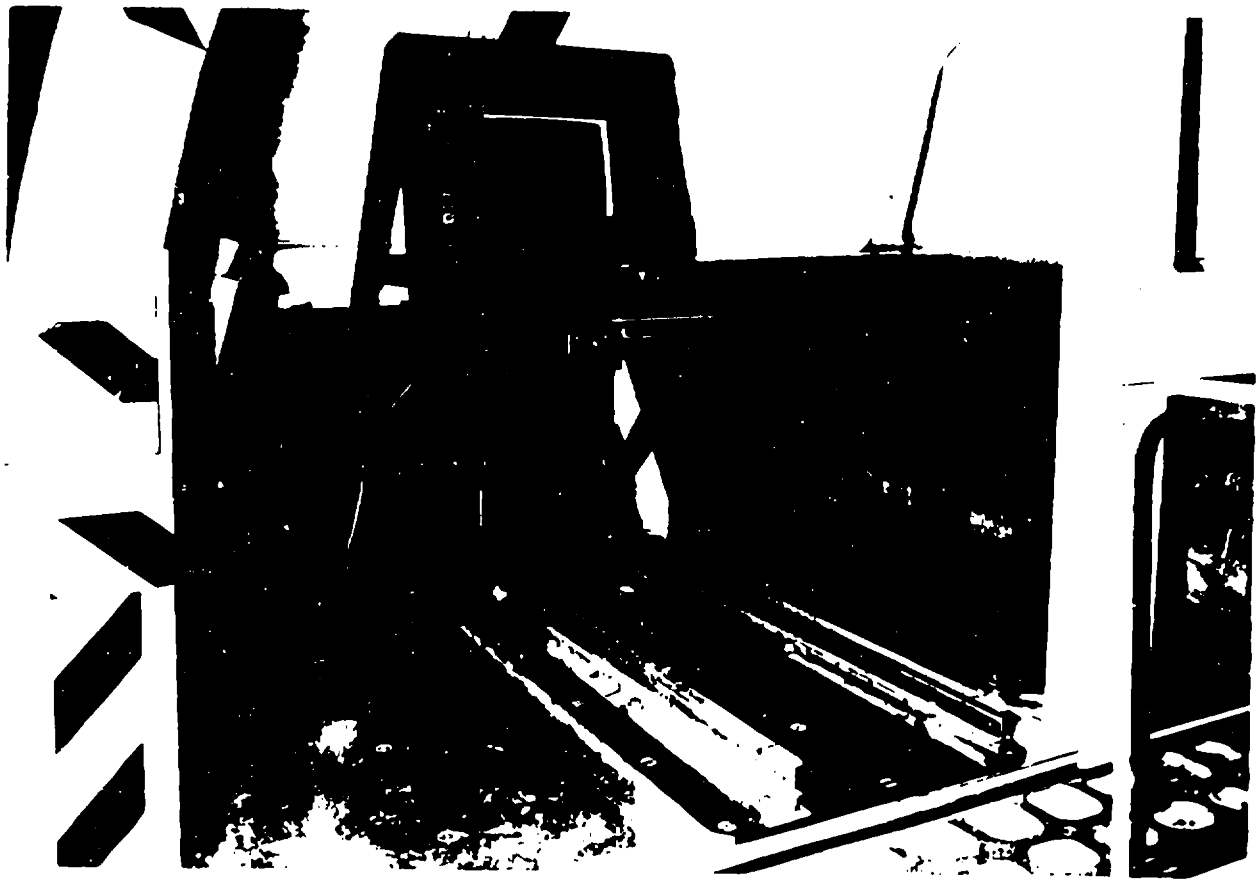


Figure 28. Custom-Built Vibration Rack.

Branch SIXMODE Vibration Faculty for five, one-hour and one, two-hour training sessions. During the first five sessions, participants were instructed how to correctly fill out the three subjective questionnaires and perform the four performance tests. Then each subject was briefed on the purpose and use of the spinal contour measurement device and was shown the proper technique for data collection purposes. Following these instructions, each subject accomplished several test sessions in each aircrew seat. The subjects were allowed to wear whatever clothes they had on at the time and, although the cockpit area of the vibration table was used for testing, no vibration exposure was experienced. During the first five sessions, experimenter coaching was used to aid the subjects in learning the tasks.

For the last (2 hr) practice test session, subjects were exposed to a full vibration run identical to the actual testing. Each participant was required to wear the flight suit, flight boots, aircrew headsets and other required clothing. The subject was then briefed on the experiment, measured on the spinal creep measurement device and then strapped into the aircrew seat. The experimenter then explained to the test participant that since the performance tasks were similar in difficulty to those found in training Air Force Pilots, high manual

dexterity, psychomotor skill and attention would be required. After the participant was securely strapped in and all systems were checked, the subject began the practice test session with vibration exposure.

Main experiment. After the test participants had accomplished the six practice test sessions, they were ready for the actual experiment. Prior to suiting up in the flight gear, each subject stripped to the waist so that an initial spinal creep measurement could be taken. The subjects were then instructed to suit up in their flight gear and secure themselves using the crew restraint systems on the aircrew seat (Figure 29). The vibration table and equipment were checked while the color monitor and control stick were tested. The subjects were run through each performance task prior to the onset of the vibration exposure to facilitate the transition to the vibration environment. The experiment was then started.

Each trial of the vibration testing comprised of three data collection phases which were intended to simulate different levels of workload during an actual mission sortie. Initially, the test participant was required to fill out the Aircrew General Comfort Form, followed by the Aircrew Body Discomfort Survey. After accomplishing these questionnaires, the subject was

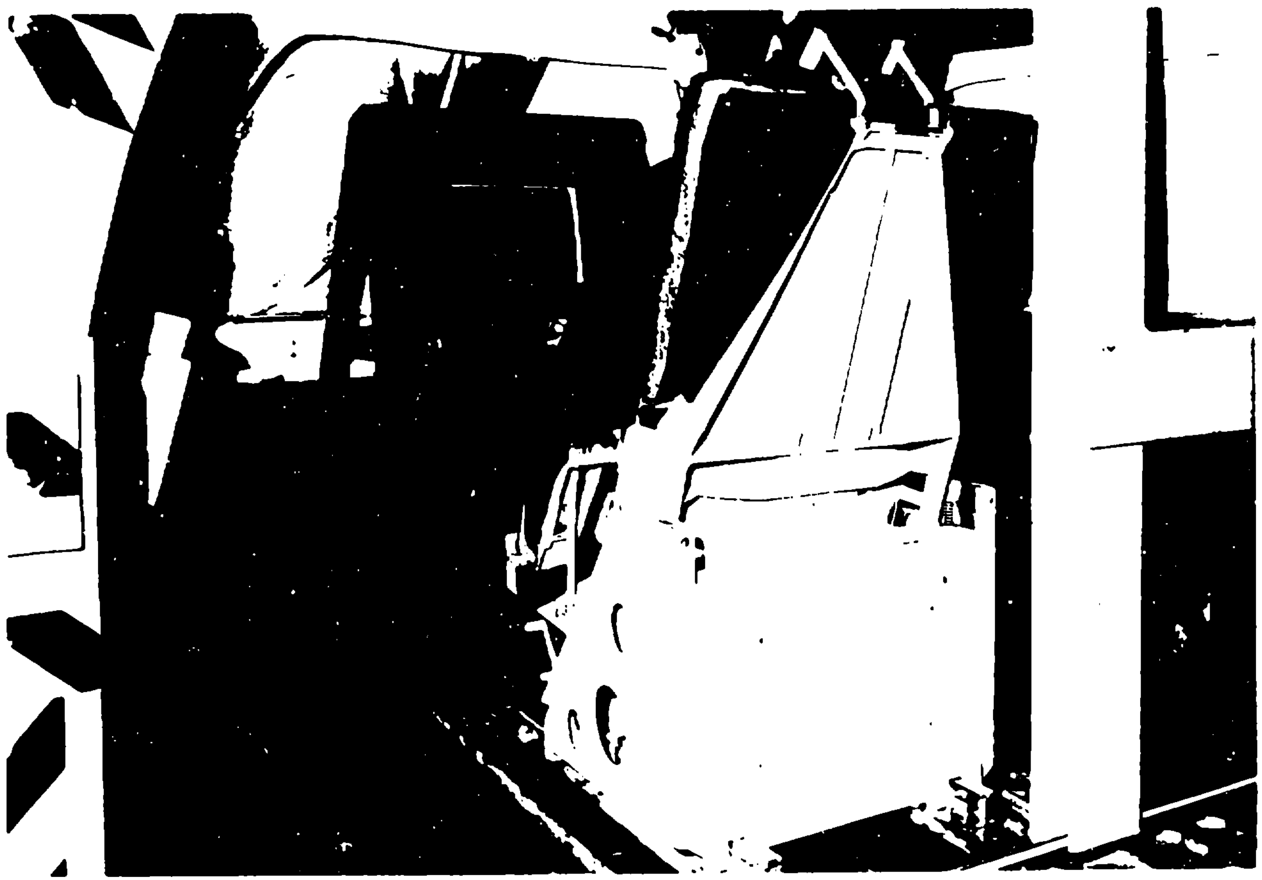


Figure 29. Subject Seated in Cockpit.

instructed to begin the human performance task which was presented on his color monitor screen. Three human performance tasks were accomplished at this time, they were: Memory Search Task, Pattern Comparison and Combined Memory Search - Tracking task. The order of presentation of these tasks was random. Following the end of the three "high workload" tasks, the subject was required to perform a moderate workload tracking task. This task continued for 25 minutes. At the completion of 25 minutes of tracking, the subject began the second data collection phase. The second data collection phase was identical to the first. The two surveys were filled out followed by the three performance tasks, ending with the twentyfive minute tracking task.

The third data collection phase began with the completion of the second phase tracking task. The third phase of the data collection effort was identical to the first two except that after the two surveys had been accomplished and the human performance tests completed, the vibration exposure was terminated and the participant was asked to fill out the Aircrew Seat Feature Checklist while feelings and thoughts concerning the aircrew seat were still vivid in his mind. After completion of the checklist, the subject was allowed to egress the aircrew seat and get down off the vibration table. The

participant was immediately ushered to the spinal contour measuring device for a post spinal creep measurement (Figure 30). After all three treatments had been completed, the subject was asked to fill out the Post Test questionnaire. This completed the experiment. Only one vibration exposure could be accomplished at a time, and since each data collection phase lasted at least 2.5 hours, plus equipment rearrangement, only two test participants could be scheduled per day.

Description of Experimental Exposure

A sum-of-sines program was used to generate vibrations which approximated the power spectral density (PSD) distribution of a C-130 flying a low level mission. Appendix C contains a sample of what the actual PSDs looked like. The vibration stimuli was limited to Z-axis (vertical) accelerations. The basic parameters of the vibration included a frequency range from 2.0 to 20 Hz with RMS accelerations not to exceed 0.5 Gz. The vibration stimuli would not exceed the exposure limits specified in MIL-STD-1472C.

In the unlikely event that an acceleration was produced that exceeded the automatic shutdown limits for any of the six degrees-of-freedom, the machine would have automatically been brought to a stop. A test would also

Figure 30. Post Spinal Creep Measurement.

have been terminated if the SIXMODE operator, test monitor, stripchart operator, or test administrator detected any equipment, procedural, or environmental problems that could have interfered with the proper operation of the vibration equipment or jeopardized the subject's safety. The test participant was free to terminate the test at any time, for any reason, by a verbal command to the SIXMODE operator via the headset.

Experimental Design

A total of twelve right-handed male Air Force personnel participated in the aircrew seat vibration exposure experiment. Each subject experienced three different treatments with no replications. Four 3x3 Latin square design experiments (cross-over design) were used to block both subjects and experimental order, in an effort to eliminate any training effects. This design is often used when a Latin square is needed in a repeated measures study to balance the order positions of treatments, yet more subjects are required than needed for a single Latin square (Neter and Wasserman, 1974). The procedure for determining a Latin square design and selecting the order of the rows, columns and alphanumerics randomly is described in detail by Fischer and Yates (1963). In the Latin square, the rows were

representative of the test participants, the columns the order of treatment and the alphanumerics were the actual treatments.

Method of Evaluation

Similar to Congleton's (1983) work in evaluating chairs, three C-130 aircrew seats were studied to determine their effects on human performance. In addition, the data from the Aircrew General Comfort Rating, Body Part Discomfort Survey, Chair Feature Checklist and Post Test questionnaires were also analyzed.

The statistical model for a Latin square (Montgomery, 1976) is:

$$Y_{ijk} = U + A_i + T_j + B_k + E_{ijk}$$

where: $i = 1,2, \ldots, p$

$j = 1,2, \ldots, p$

$k = 1,2, \ldots, p$

where: -Y_{ijk} is the observation in the ith row and the kth column for the jth treatment

-U is the overall mean

-A_i is the ith row effect

-T_j is the jth treatment effect

-B_k is the kth column effect

-E_{ijk} is the random error

-the model is completely additive

-there is no interaction between rows, columns and treatments

An analysis of variance (ANOVA) was accomplished for each of the variables involved in the vibration experiment. Significant differences between expected mean squares were determined using the Duncan Multiple Range Test (Montgomery, 1976) at the .05 level of significance.

This ends the methodology section of experiment no. 1. The following section outlines what was done in experiment no. 2.

EXPERIMENT NO. 2: STATIC PRESSURE ANALYSIS

Experiment No. 2 was specifically designed to collect maximum seat pan pressure data generated when an individual's buttocks and thighs contacted the seat cushion of the aircrew seat under investigation. Since the equipment used identified the magnitude of the maximum pressure that occurred on the body contact area without prior judgement on the location of the maximum

pressure, the various tests performed ensured that pressure was relieved over the susceptible area and was not merely being transferred to a different location (Krouskop, 1983).

Test Participants

The test participants were recruited from the graduate and undergraduate Industrial Engineering Program at Texas A&M University. Fifteen male subjects between the ages of 22 and 45, volunteered to participate in this study. Males were selected because the Air Force pilot population is primarily male and also to ensure standardization of the experiment since there are structural differences between the female and male pelvises (Moore, 1980).

Variables

The dependent variables in this experiment were:

1. Maximum seat pan pressure data collected in millimeters of mercury (mm Hg)

The independent variables in this experiment were:

1. The current AMI C-130 aircrew seat

2. The current AMI C-130 aircrew seat with Confor foam (CURRENT-CONF)
3. The modified (MOD-REG) C-130 aircrew seat
4. The modified (MOD-CONF) C-130 aircrew seat

Equipment

The main piece of equipment used in Experiment No. 2 was the Texas Interface Pressure Evaluator (TIPE) (Figure 31). The TIPE system was comprised of five major parts (Krouskop, 1983).

1. Transducer Pad
2. Cable Assembly
3. Display Unit
4. Inflator Bulb
5. Spectral sensitivity/threshold adjustment tool

The transducer pad consisted of two layers of flexible vinyl and had a total of 144 pneumatically activated switches spaced 2.9 cm apart on an internally located circuit board. Although the 12 x 12 matrix of sensors encompassed a 30 cm x 30 cm area, the overall pad was 41 cm x 46 cm. Each of the 144 switches was linked to a corresponding light emitting diode (LED) on the readout display unit. An individual LED was activated when the inflation pressure on the inside of

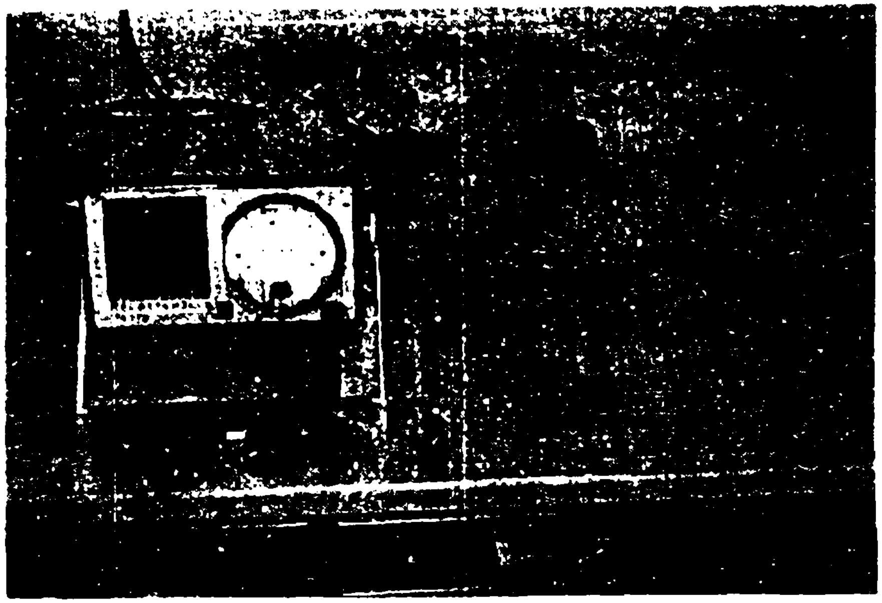


Figure 31. Texas Interface Pressure Evaluator.

the pad was less than the pressure applied locally on the exterior. The pressure was indicated by a pressure manometer which was spliced into the typical readout display unit. This allowed for higher pressure readings than was possible on the regular TIPE pressure guage. An inflator bulb provided the mean to inflate/deflate the transducer pad. (Reger, Chung and Martin, 1985; Garber and Krouskop, 1984; Krouskop, 1983; Garber, Krouskop and Carter, 1978). A more indepth component description and use of the TIPE is contained in Appendix D. The three aircrew seats, as described previously, were used during this experiment. A color video camera and portable VHS video cassette recorder were used to record the pressure data and to document the time interval from maximum pressure to the minimum pressure reading.

Procedure

The test participants were instructed to report to the Human Factors Engineering Laboratory, Zachry Engineering Building, Texas A&M University at predetermined times. Upon their arrival, the participants were instructed to adhere to the following experimental procedures:

1. The subject was instructed to wear hospital pants, boxer shorts and a shirt as provided by the experimenter.
2. The pressure pad was placed between the test participant and the seat cushion/pan being evaluated. The pad was positioned such that the alignment of ischial tuberosities and the thigh area corresponded to the appropriate area on the display unit.
3. The subject was instructed to remain as motionless as possible after the experimenter had determined he was positioned correctly. This included having the upper arms hang naturally at the side with the hands being clasped in the lap area.
4. After 15 minutes, air was pumped into the pad via the inflator bulb until all LED's on the display area were no longer illuminated.
5. The video camera and recorder were directed at the TIPE and turned on.
6. The air was slowly bled out, from a condition of maximum pressure, where no lights were illuminated on the display screen, to a condition of minimum pressure, where a majority of the LED were illuminated.

7. After the air was bled out, the video recorder and camera were turned off and the video tape was retained for data analysis.

Experimental Design

A total of fifteen male participants took part in the experiment involving the measurement of the seat pan pressures. Each subject experienced four treatments with no replication. A Randomized Complete Block design was used to make the experimental error as small as possible, thereby removing the variability between subjects from the experimental error. The statistical model for the Randomized Complete Block design (Montgomery, 1976) is:

$$Yij = U + Ti + Bj + Eij$$

where: $i = 1, 2, \ldots, p$

$j = 1, 2, \ldots, p$

where:
- -U is an overall mean
- -T is the effort of the ith treatment
- -Bj is the effect of the jth block
- -Eij is the random error

Method of Evaluation

The four aircrew seat design types were analyzed to determine the effect of seat pan configuration on maximum seat pan pressure. The Randomized Complete Block design was implemented to control sources of variability through the use of blocking. Significant differences between expected mean squares were determined using the Duncan Multiple Range Test (Montgomery, 1976) at the .05 level of significance.

CHAPTER IV

RESULTS

RESULTS OF EXPERIMENT NO. 1

Human Performance

During each vibration test, the four performance tasks were presented to the subjects at three different times. After an inital warm up session, the vibration environment was generated and the initial (period 1) data was collected. Forty-five minutes later, the second group of data was collected (period 2). After an hour and a half, the third and final data collection (period 3) was performed. Table 1 presents a summary of all of the performance data collected during the vibration study.

Only the Pattern Comparison Task showed significant differences. The ANOVA results in Table 2 indicate that subjects sitting in either of the modified aircrew seats were able to recognize more correct patterns than when they were seated in the current AMI aircrew seat. During the third period, subjects sitting in the modified aircrew seats performed better than when seated in the AMI seat. The data for the human performance tasks can be found in Appendix E.

TABLE 1

Summary of Performance Analyses

PERFORMANCE TASK	PERIOD 1*	PERIOD 2*	PERIOD 3*
<u>Memory Search Task</u>			
mean reaction time for probes correctly ID	NS(0.3754)	NS(0.6548)	NS(0.1583)
mean reaction time for all probes ID	NS(0.2245)	NS(0.6605)	NS(0.1448)
number of probes correctly ID	NS(0.0969)	NS(0.2991)	NS(0.0754)
<u>Pattern Comparison Task</u>			
mean reaction time for patterns correctly ID	NS(0.6833)	NS(0.6972)	NS(0.6453)
mean reaction time for all patterns ID	NS(0.7101)	NS(0.5428)	NS(0.6162)
number of patterns correctly ID	NS(0.1874)	S(0.0111)	NS(0.4354)

* S/NS(PR>F) - Significant/ Non-Significant (Probability).

TABLE 1 (continued).

PERFORMANCE TASK	PERIOD 1*	PERIOD 2*	PERIOD 3*
<u>Combined Memory Search-Tracking Task</u>			
mean reaction time for probes correctly ID	NS(0.0766)	NS(0.6642)	NS(0.4526)
mean reaction time for all probes ID	NS(0.0752)	NS(0.5269)	NS(0.3738)
RMS offset from center	NS(0.7042)	NS(0.7027)	NS(0.6993)
number of boundary hits	NS(0.8203)	NS(0.9294)	NS(0.7903)
<u>Critical Tracking Task</u>			
RMS offset from center	NS(0.5433)	NS(0.1396)	--.--
number of boundary hits	NS(0.5254)	NS(0.2392)	--.--

* S/NS(PR>F) - Significant/ Non-Significant (Probability).

--.-- - Critical Tracking Task was only performed twice during each treatment.

TABLE 2

Pattern Comparison Task. ANOVA and Duncan's Multiple Range Test

SOURCE OF VARIATION	DF	SUM OF SQUARES	F RATIO	LEVEL OF SIGNIFICANCE
Subject	11	114.8889	4.01	0.0035
Seat	2	29.5556	5.68	0.0111
Order	2	8.3889	1.61	0.2244

DUNCAN'S GROUPING*	MEAN**	N	SEAT TYPE
A	58.6667	12	MOD-REG
A			
A	57.1667	12	MOD-CONF
B	56.5000	12	CURRENT

* Means with the same letter are not significantly different at alpha = 0.05, df = 20, and mean square error = 2.60278.

** Number of probes correctly identifed.

Subjective Surveys

Aircrew general comfort. Aircrew General Comfort Rating questionnaires were completed by subjects prior to each of the three measurement periods. The graph in Figure 32 illustrates quite clearly the differences in general comfort as a function of time. It was apparent from the graph that the level of discomfort experienced by subjects while seated in the current seat was much greater than when seated in the two modified aircrew seats. This is substantiated by the results presented in Table 3, 4, and 5. Each of these tables presents results which indicate that aircrew seat type showed statistically significant differences in each of the three time periods. Also, each of these tables indicate that there are no statistically significant differences between the MOD-REG and MOD-CONF aircrew seats, however the current AMI aircrew seat ratings were higher (less satisfactory) than either the MOD-REG or MOD-CONF in all three time periods. The raw data for the Aircrew General Comfort rating can be found in Appendix E.

Aircrew body part discomfort. An Aircrew Body Part Discomfort Survey was completed by subjects after the Aircrew General Comfort Rating questionnaire, but prior to each of the three human performance measurement

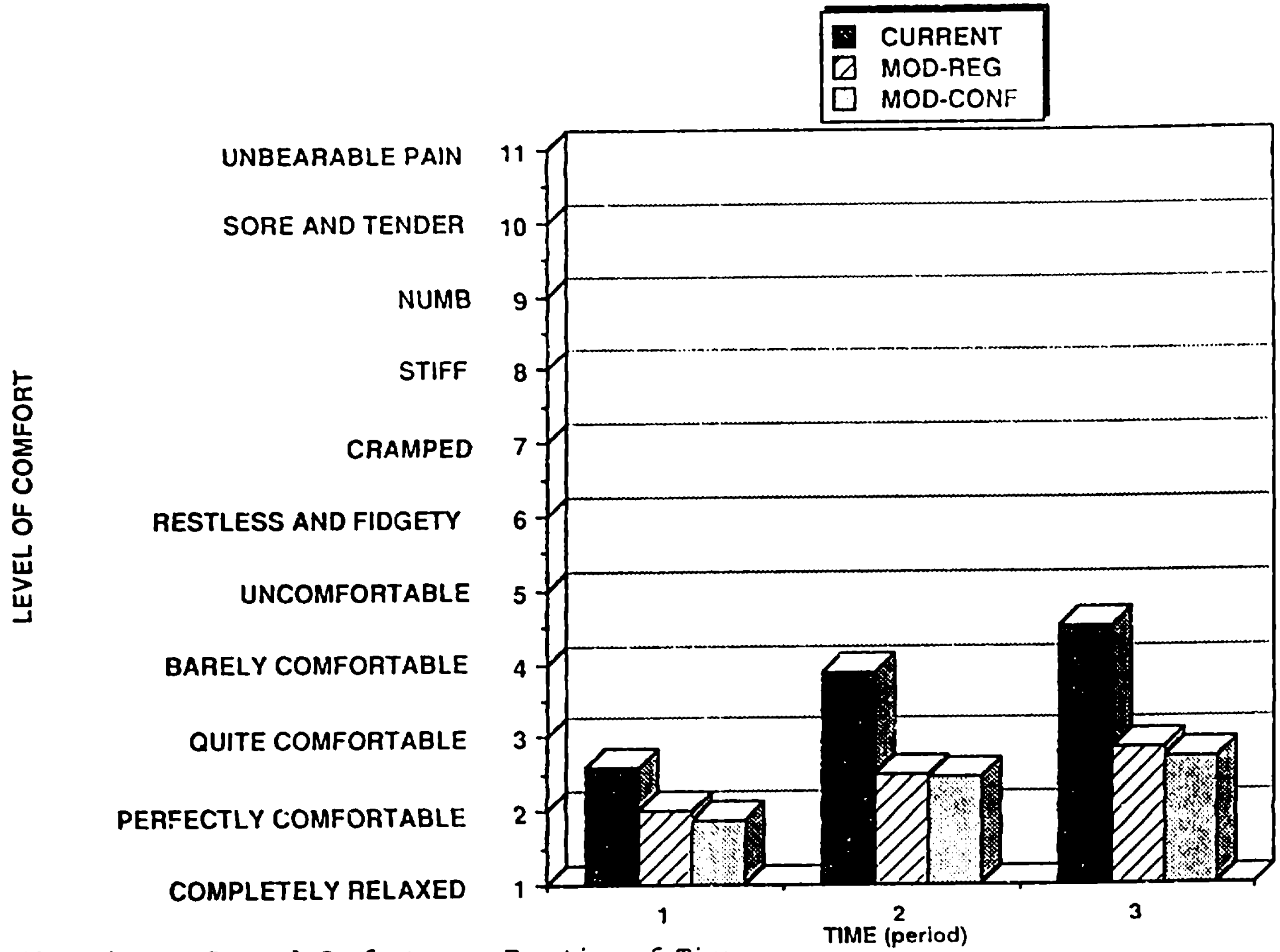


Figure 32. Aircrew General Comfort as a Function of Time.

TABLE 3

Aircrew General Comfort Rating - Period 1. ANOVA and Duncan's Multipie Range Test

SOURCE OF VARIATION	DF	SUM OF SQUARES	F RATIO	LEVEL OF SIGNIFICANCE
Subject	11	11.9800	4.47	0.0018
Seat	2	3.4867	7.16	0.0045
Order	2	0.4850	1.00	0.3869

DUNCAN'S GROUPING*	MEAN**	N	SEAT TYPE
A	2.6000	12	CURRENT
B	2.0167	12	MOD-REG
B			
B	1.8833	12	MOD-CONF

* Means with the same letter are not significantly different at alpha = 0.05, df = 20, and mean square error = 0.243417.

** Where 1 = completely relaxed
2 = perfectly comfortable
3 = quite comfortable
4 = barely comfortable
5 = uncomfortable

TABLE 4

Aircrew General Comfort Rating - Period 2. ANOVA and Duncan's Multiple Range Test

SOURCE OF VARIATION	DF	SUM OF SQUARES	F RATIO	LEVEL OF SIGNIFICANCE
Subject	11	9.6922	3.62	0.0061
Seat	2	15.7739	32.40	0.0001
Order	2	1.4906	3.06	0.0692

DUNCAN'S GROUPING*	MEAN**	N	SEAT TYPE
A	3.8750	12	CURRENT
B	2.4750	12	MOD-REG
B			
B	2.4667	12	MOD-CONF

* Means with the same letter are not significantly different at alpha = 0.05, df = 20, and mean square error = 0.24344.

** Where 1 = completely relaxed
2 = perfectly comfortable
3 = quite comfortable
4 = barely comfortable
5 = uncomfortable

TABLE 5

Aircrew General Comfort Rating - Period 3. ANOVA and Duncan's Multiple Range Test

SOURCE OF VARIATION	DF	SUM OF SQUARES	F RATIO	LEVEL OF SIGNIFICANCE
Subject	11	16.1164	5.74	0.0004
Seat	2	23.8406	46.73	0.0001
Order	2	1.0172	1.99	0.1624

DUNCAN'S GROUPING*	MEAN**	N	SEAT TYPE
A	4.5167	12	CURRENT
B	2.8750	12	MOD-REG
B			
B	2.7167	12	MOD-CONF

* Means with the same letter are not significantly different at alpha = 0.05, df = 20, and mean square error = 0.25511.

** Where 1 = completely relaxed
2 = perfectly comfortable
3 = quite comfortable
4 = barely comfortable
5 = uncomfortable

periods. Table 6 provides a summary of all Aircrew Body Part Discomfort analyses. Statistically significant differences were noticed in all three periods for the buttocks and also in period 2 for the thighs.

In the first period, the difference between buttocks discomfort levels, for the various seats, were immediately obvious, as presented by Table 7. From the very beginning, the current aircrew seat was statistically different from the other seats. Continuing on into the second period, the difference between the current, MOD-REG and MOD-CONF became even more pronounced as indicated by Table 8. In the third and final period (Table 9), the pain and discomfort associated with the current aircrew seat had left the other two far behind, making the subject more than willing to end the test and egress from the current seat.

Significant differences in thigh discomfort ratings were noted during period 2. As indicated by Table 10, the current aircrew seat was significantly different from the MOD-REG and MOD-CONF. It is interesting to note that this condition did not occur in the third period, suggesting that the subjects changed their posture to alleviate the pain.

The Duncan's Groupings, presented in Table 7 though 10, highlighted that the MOD-CONF and MOD-REG aircrew

TABLE 6

Summary of Aircrew Body Part Discomfort Analyses

BODY PART	PERIOD 1*	PERIOD 2*	PERIOD 3*
Neck	NS(0.3191)	NS(0.1094)	NS(0.8581)
Shoulders	NS(-.-----)	NS(0.1343)	NS(0.8963)
Upper Back	NS(-.-----)	NS(0.3039)	NS(0.0922)
Upper Arms	NS(-.-----)	NS(-.-----)	NS(-.-----)
Mid Back	NS(-.-----)	NS(0.5987)	NS(0.3304)
Lower Arms	NS(0.3855)	NS(0.3855)	NS(0.1594)
Lower Back	NS(0.3356)	NS(0.0765)	NS(0.0848)
Buttocks	S(0.0014)	S(0.0001)	S(0.0001)
Hands	NS(-.-----)	NS(0.7496)	NS(0.0796)
Thighs	NS(-.-----)	S(O.O490)	NS(0.2054)
Knees	NS(-.-----)	NS(-.-----)	NS(0.2054)
Lower Legs	NS(-.-----)	NS(0.3855)	NS(0.3855)

* S/NS(PR>F) - Significant/ Non-Significant (Probability).

-.----- - No response of pain/discomfort for any of the seats.

TABLE 7

Aircrew Body Part Discomfort Rating for Buttocks - Period 1. ANOVA and Duncan's Multiple Range Test

SOURCE OF VARIATION	DF	SUM OF SQUARES	F RATIO	LEVEL OF SIGNIFICANCE
Subject	11	3.3408	1.42	0.2387
Seat	2	3.9617	9.26	0.0014
Order	2	1.4867	3.47	0.0507

DUNCAN'S GROUPING*	MEAN**	N	SEAT TYPE
A	0.7417	12	CURRENT
B	0.0833	12	MOD-REG
B			
B	0.0000	12	MOD-CONF

* Means with the same letter are not significantly different at alpha = 0.05, df = 20, and mean square error = 0.213917.

** Where 0 = no pain/discomfort
1 = just noticable pain/discomfort
5.5 = moderate pain/discomfort
11 = intolerable pain/discomfort

TABLE 8

Aircrew Body Part Discomfort Rating for Buttocks - Period 2. ANOVA and Duncan's Multiple Range Test

SOURCE OF VARIATION	DF	SUM OF SQUARES	F RATIO	LEVEL OF SIGNIFICANCE
Subject	11	9.3989	1.14	0.3839
Seat	2	55.5356	37.03	0.0001
Order	2	2.0005	1.33	0.2859

DUNCAN'S GROUPING*	MEAN**	N	SEAT TYPE
A	2.7833	12	CURRENT
B	0.2000	12	MOD-REG
B			
B	0.1000	12	MOD-CONF

* Means with the same letter are not significantly different at alpha = 0.05, df = 20, and mean square error = 0.749861.

** Where 0 = no pain/discomfort
1 = just noticable pain/discomfort
5.5 = moderate pain/discomfort
11 = intolerable pain/discomfort

TABLE 9

Aircrew Body Part Discomfort Rating for Buttocks - Period 3. ANOVA and Duncan's Multiple Range Test

SOURCE OF VARIATION	DF	SUM OF SQUARES	F RATIO	LEVEL OF SIGNIFICANCE
Subject	11	16.4164	1.38	0.2555
Seat	2	136.7822	63.26	0.0001
Order	2	0.1756	0.08	0.9223

DUNCAN'S GROUPING*	MEAN**	N	SEAT TYPE
A	4.8750	12	CURRENT
B	0.8083	12	MOD-CONF
B			
B	0.6750	12	MOD-REG

* Means with the same letter are not significantly different at alpha = 0.05, df = 20, and mean square error = 1.08111.

** Where 0 = no pain/discomfort
1 = just noticable pain/discomfort
5.5 = moderate pain/discomfort
11 = intolerable pain/discomfort

TABLE 10

Aircrew Body Part Discomfort Rating for Thighs - Period 2.
ANOVA and Duncan's Multiple Range Test

SOURCE OF VARIATION	DF	SUM OF SQUARES	F RATIO	LEVEL OF SIGNIFICANCE
Subject	11	1.7822	1.06	0.4361
Seat	2	1.0756	3.52	0.0490
Order	2	0.5089	1.67	0.2143

DUNCAN'S GROUPING*	MEAN**	N	SEAT TYPE
A	0.3667	12	CURRENT
B	0.0000	12	MOD-REG
B			
B	0.0000	12	MOD-CONF

* Means with the same letter are not significantly different at alpha = 0.05, df = 20, and mean square error = 0.152778.

** Where 0 = no pain/discomfort
1 = just noticable pain/discomfort
5.5 = moderate pain/discomfort
11 = intolerable pain/discomfort

seats were more effective in reducing discomfort than the current aircrew seat. Additionally, the mean discomfort level for the MOD-CONF seat was always less than the MOD-REG, with the exception of the buttock value for period 3. Figure 33 provides a view of the seat differences during the third period, which is the most critical in terms of body part discomfort. The raw data for the Body Part Discomfort Surveys can be found in Appendix E.

<u>Aircrew Seat Feature Checklist.</u> Aircrew Seat Feature Checklists were accomplished by each subject immediately following the termination of the vibration exposure. Table 11 summarizes the responses to the Aircrew Seat Feature Checklist. All of the seat features, with the exception of seat pan height, seat pan length, seat pan slope and adjustability of backrest, proved to be statistically significant. The raw data for the Aircrew Seat Feature Checklist can be found in Appendix E.

During the seat evaluations, the MOD-CONF aircrew seat was determined to be the most correct size as far as seat width was concerned, with the MOD-REG seat a very close second (Table 12). The current AMI seat was evaluated as being a little too narrow by most subjects.

The shape of the seat pan (which was essentially the same design for both the MOD-CONF and MOD-REG, with the

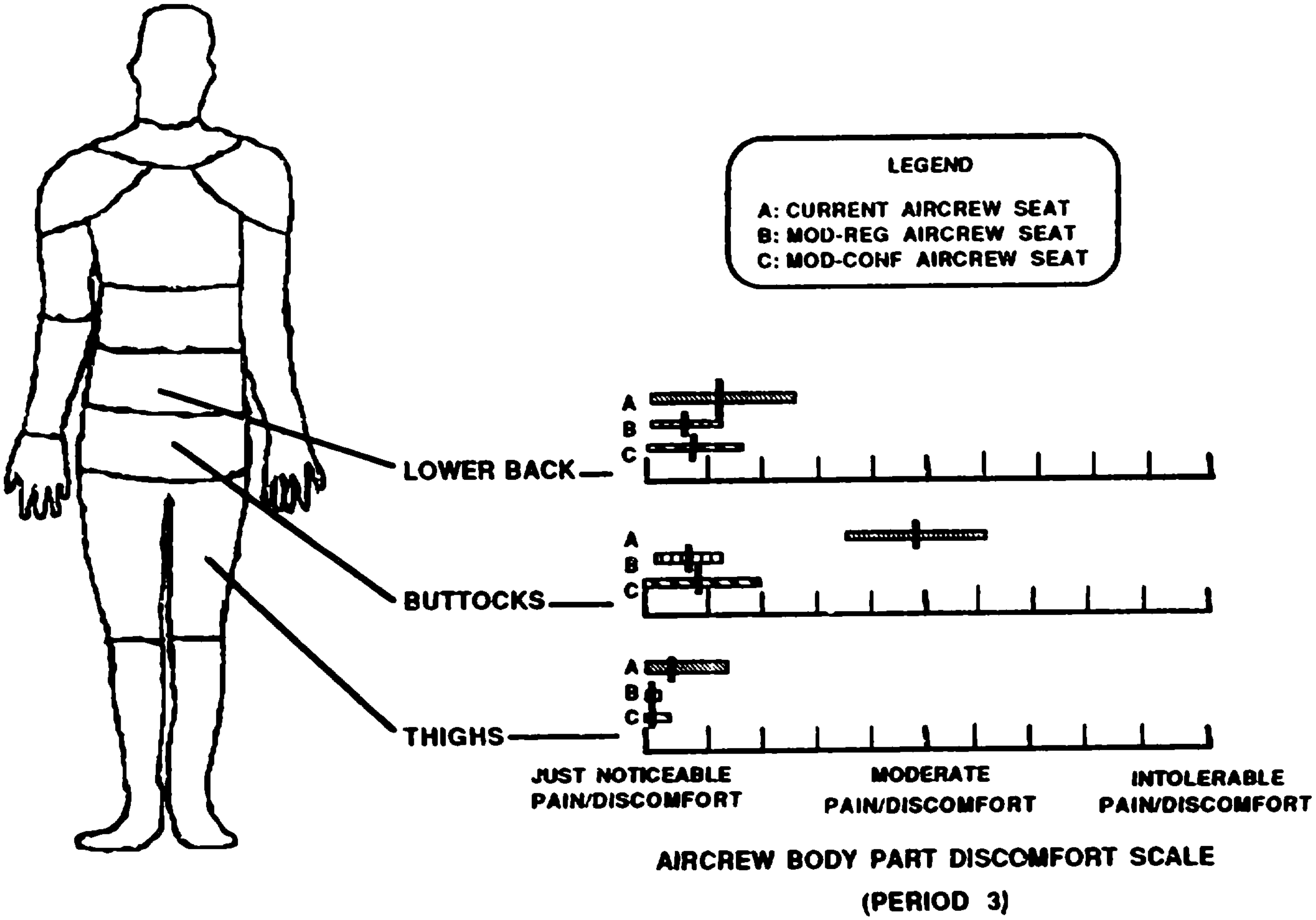


Figure 33. Aircrew Body Part Discomfort Scale - Period 3.

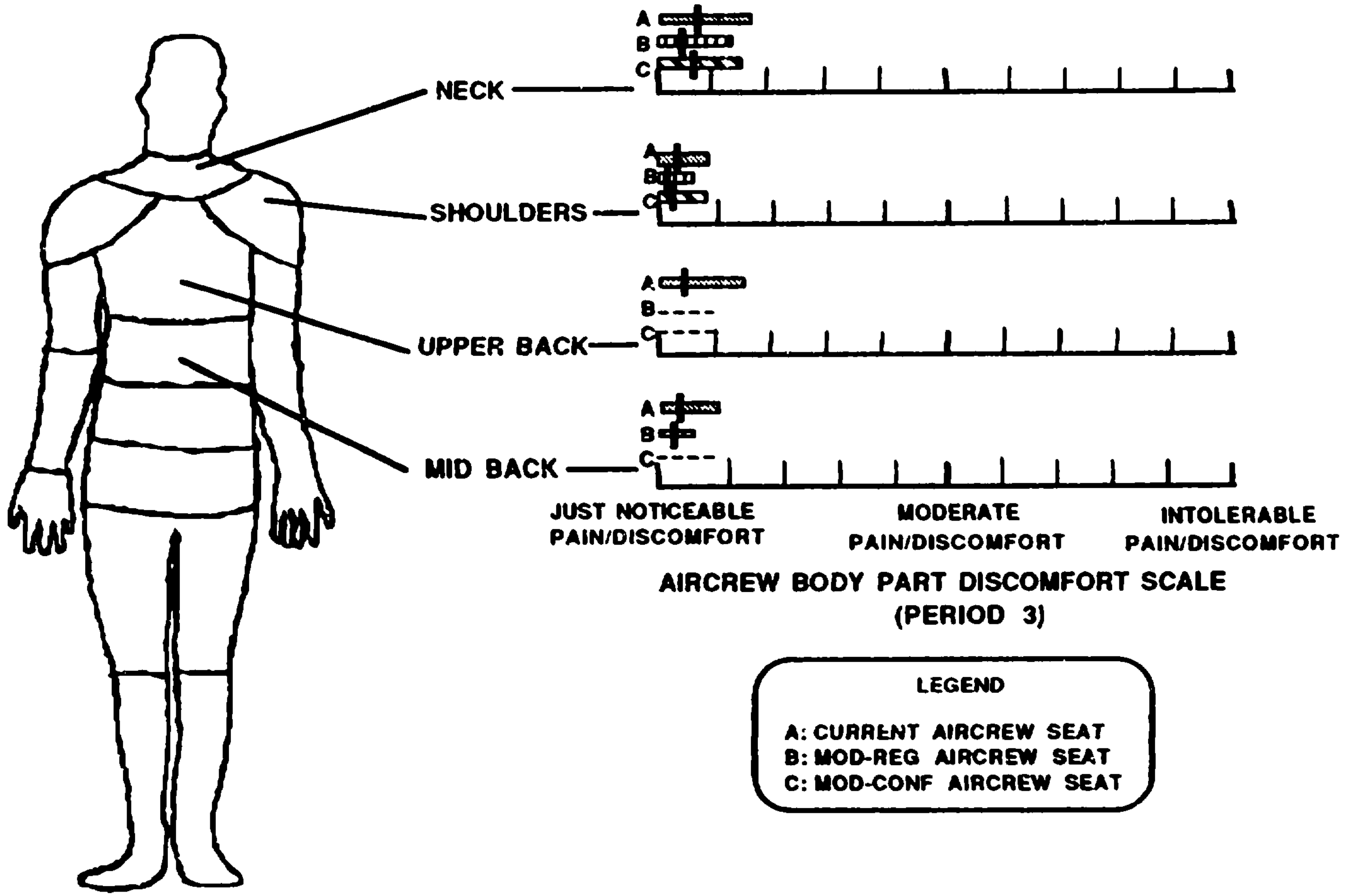


Figure 33. (Continued).

TABLE 11

Summary of Aircrew Seat Feature Checklist Analyses

SEAT FEATURES	PERIOD 3*
Seat Pan Height	NS(0.6173)
Seat Pan Length	NS(0.7297)
Seat Pan Width	S(0.0161)
Seat Pan Slope	NS(0.1505)
Seat Pan Shape	S(0.0001)
Seat Pan Padding	S(0.0001)
Backrest Adjustability	NS(0.2208)
Backrest Shape	S(0.0001)
Backrest Curvature	S(0.0273)
Lumbar Support	S(0.0001)
Backrest Padding	S(0.0139)
Overall Opinion	S(0.0001)

* S/NS(PR>F) - Significant/ Non-Significant (Probability).

TABLE 12

Aircrew Seat Feature Checklist for Seat Pan Width.
ANOVA and Duncan's Multiple Range Test

SOURCE OF VARIATION	DF	SUM OF SQUARES	F RATIO	LEVEL OF SIGNIFICANCE
Subject	11	20.3897	2.00	0.0858
Seat	2	9.4772	5.11	0.0161
Order	2	3.4072	1.84	0.1850

DUNCAN'S GROUPING*	MEAN**	N	SEAT TYPE
A	5.7833	12	MOD-REG
A			
A	5.5333	12	MOD-CONF
B	4.5917	12	CURRENT

* Means with the same letter are not significantly different at alpha = 0.05, df = 20, and mean square error = 0.926778.

** Where 1 = too narrow
5.5 = correct
11.0 = too wide

exception of the foam padding) was determined to be a very good fit for both the MOD-CONF and MOD-REG (Table 13). The current aircrew seat was evaluated as being less than adequate.

Seat pan padding was another area where the current aircrew seat suffered major short-comings. Table 14 presents results which indicate that both the MOD-CONF and MOD-REG seat pans were very close to being correctly padded, whereas the AMI seat pan was in definite need of more padding or padding of a different variety.

Several backrest features were also statistically responsive to seat type. The evaluation of backrest shape (Table 15) indicated that the MOD-CONF and MOD-REG backrests were a good fit, whereas the current backrest was rated at less than adequate.

Table 16 presents the results of the backrest curvature evaluation. Both the MOD-CONF and MOD-REG backrest curvatures were described as being approximately correct and the current AMI backrest curvature was rated as being a little too flat.

The evaluation of lumbar support, Table 17, showed a marked difference between the two modified aircrew seats and the current seat. Both the MOD-CONF and MOD-REG had lumbar support built into the backrest, whereas what little lumbar support the current seat had was integrated

TABLE 13

Aircrew Seat Feature Checklist for Shape of Seat Pan.
ANOVA and Duncan's Multiple Range Test

SOURCE OF VARIATION	DF	SUM OF SQUARES	F RATIO	LEVEL OF SIGNIFICANCE
Subject	11	80.1889	2.99	0.0162
Seat	2	148.2406	30.37	0.0001
Order	2	0.2606	0.05	0.9482

DUNCAN'S GROUPING*	MEAN**	N	SEAT TYPE
A	8.3500	12	MOD-CONF
A			
A	8.2750	12	MOD-REG
B	4.0083	12	CURRENT

* Means with the same letter are not significantly different at alpha = 0.05, df = 20, and mean square error = 2.44061.

** Where 1 = poor fit
5.5 = adequate
11.0 = fits well

TABLE 14

Aircrew Seat Feature Checklist for Seat Pan Padding.
ANOVA and Duncan's Multiple Range Test

SOURCE OF VARIATION	DF	SUM OF SQUARES	F RATIO	LEVEL OF SIGNIFICANCE
Subject	11	3.7622	1.56	0.1858
Seat	2	134.1006	306.36	0.0001
Order	2	2.3022	5.26	0.0146

DUNCAN'S GROUPING*	MEAN**	N	SEAT TYPE
A	5.9250	12	MOD-REG
A			
A	5.7583	12	MOD-CONF
B	1.7500	12	CURRENT

* Means with the same letter are not significantly different at alpha = 0.05, df = 20, and mean square error = 0.218861.

** Where 1 = needs more
5.5 = correct
11.0 = needs less

TABLE 15

Aircrew Seat Feature Checklist for Shape of Backrest.
ANOVA and Duncan's Multiple Range Test

SOURCE OF VARIATION	DF	SUM OF SQUARES	F RATIO	LEVEL OF SIGNIFICANCE
Subject	11	121.9300	9.09	0.0001
Seat	2	56.2850	23.02	0.0001
Order	2	0.4017	0.16	0.8497

DUNCAN'S GROUPING*	MEAN**	N	SEAT TYPE
A	7.9583	12	MOD-CONF
A			
A	7.6333	12	MOD-REG
B	5.1583	12	CURRENT

* Means with the same letter are not significantly different at alpha = 0.05, df = 20, and mean square error = 1.22267.

** Where 1 = poor fit
5.5 = adequate
11.0 = fits well

TABLE 16

Aircrew Seat Feature Checklist for Curvature of Backrest. ANOVA and Duncan's Multiple Range Test

SOURCE OF VARIATION	DF	SUM OF SQUARES	F RATIO	LEVEL OF SIGNIFICANCE
Subject	11	23.1031	3.03	0.0045
Seat	2	4.7539	4.34	0.0273
Order	2	0.6289	0.57	0.5725

DUNCAN'S GROUPING*	MEAN**	N	SEAT TYPE
A	5.7583	12	MOD-REG
A			
A	5.7500	12	MOD-CONF
B	4.9833	12	CURRENT

* Means with the same letter are not significantly different at alpha = 0.05, df = 20, and mean square error = 0.548194.

** Where 1 = too flat
5.5 = correct
11.0 = too curved

TABLE 17

Aircrew Seat Feature Checklist for Lumbar Support.
ANOVA and Duncan's Multiple Range Test

SOURCE OF VARIATION	DF	SUM OF SQUARES	F RATIO	LEVEL OF SIGNIFICANCE
Subject	11	15.9789	1.10	0.4103
Seat	2	39.4572	14.92	0.0001
Order	2	3.6156	1.37	0.2777

DUNCAN'S GROUPING*	MEAN**	N	SEAT TYPE
A	5.9500	12	MOD-REG
A			
A	5.9417	12	MOD-CONF
B	3.7250	12	CURRENT

* Means with the same letter are not significantly different at alpha = 0.05, df = 20, and mean square error = 1.32236.

** Where 1 = needs more
5.5 = correct
11.0 = needs less

in the backrest structure. The MOD-CONF and MOD-REG were rated as near correct and the current seat was determined to need more lumbar support.

Backrest padding (Table 18), was another feature which was responsive to seat type. The current aircrew seat was statistically different from the other two seats, which were statistically equivalent. The current backrest was in need of a little more padding, whereas the MOD-CONF and MOD-REG were perceived as requiring a little less padding.

At the end of each vibration exposure, subjects were asked to provide an overall opinion of the aircrew seat which they had just completed testing. Table 19 provides the results of this analysis. The two modified versions were far more popular with the test participants than was the current AMI aircrew seat. The MOD-REG mean rating (9.28) and MOD-CONF (9.00) were close to the "like very much" rating (11.0), whereas the current seat mean rating (2.90) was close to the "dislike" rating (1.0) on the evaluation scale. Most individuals did not have a great deal of good to say concerning the current seat following the vibration exposure.

<u>Post Test.</u> The results of the Post Test questionnaire are presented in Table 20. From the analysis, the most preferred aircrew seat was the MOD-

TABLE 18

Aircrew Seat Feature Checklist for Backrest Padding.
ANOVA and Duncan's Multiple Range Test

SOURCE OF VARIATION	DF	SUM OF SQUARES	F RATIO	LEVEL OF SIGNIFICANCE
Subject	11	9.1722	1.16	0.3712
Seat	2	7.6739	5.34	0.0139
Order	2	0.1906	0.13	0.8766

DUNCAN'S GROUPING*	MEAN**	N	SEAT TYPE
A	6.2083	12	MOD-CONF
A			
A	5.9750	12	MOD-REG
B	5.1333	12	CURRENT

* Means with the same letter are not significantly different at alpha = 0.05, df = 20, and mean square error = 0.718778.

** Where 1 = needs more
5.5 = correct
11.0 = needs less

TABLE 19

Aircrew Seat Feature Checklist Overall Opinion.
ANOVA and Duncan's Multiple Range Test

SOURCE OF VARIATION	DF	SUM OF SQUARES	F RATIO	LEVEL OF SIGNIFICANCE
Subject	11	32.0022	2.81	0.0217
Seat	2	311.3172	150.25	0.0001
Order	2	4.9689	2.40	0.1165

DUNCAN'S GROUPING*	MEAN**	N	SEAT TYPE
A	9.2750	12	MOD-REG
A			
A	8.9917	12	MOD-CONF
B	2.9000	12	CURRENT

* Means with the same letter are not significantly different at alpha = 0.05, df = 20, and mean square error = 1.03603.

** Where 1 = dislike
5.5 = indifferent
11.0 = like very much

TABLE 20

Post Test Questionnaire. Friedman's Chi-Square Statistic and Dunn's Multiple Range Test

SOURCE OF VARIATION	DF	SUM OF SQUARES	F RATIO	LEVEL OF SIGNIFICANCE
Subject	11	0.0000	0.00	1.0000
Seat	2	19.5000	31.20	0.0001

DUNN'S GROUPING*	MEAN**	N	SEAT TYPE
A	3.0000	12	CURRENT
B	1.7500	12	MOD-REG
C	1.2500	12	MOD-CONF

* Means with the same letter are not significantly different at alpha = 0.05 and df = 20.

** Where 1 = most preferred aircrew seat
3 = least preferred aircrew seat

CONF, followed by the MOD-REG, with the current seat rated last by each participant in the experiment. In this instance, each of the aircrew seats were statistically different than each other. The raw data for the Post Test questionnaire can be found in Appendix F.

Spinal Creep

Spinal creep measurements were taken both pre- and post-test to examine any differences in spinal contour resulting from the three aircrew seats in the vibration environment. Three different variables were investigated when performing the spinal creep analyses: area under the curve from C-7 to S-1, length of the spine (curvature) from C-7 to S-1 and height of the spine (straight line) from C-7 to S-1 (Figure 34). Both area and length measurements showed statistical differences between seat types. The raw data for the spinal creep measurement can be found in Appendix G.

Looking at the spinal creep area change, Table 21, the current and MOD-REG aircrew seats were evaluated as being statistically equivalent, as were the MOD-CONF and MOD-REG. This generated a situation where the current and MOD-CONF were significantly different, however the MOD-REG was non-discriminable from either. The results

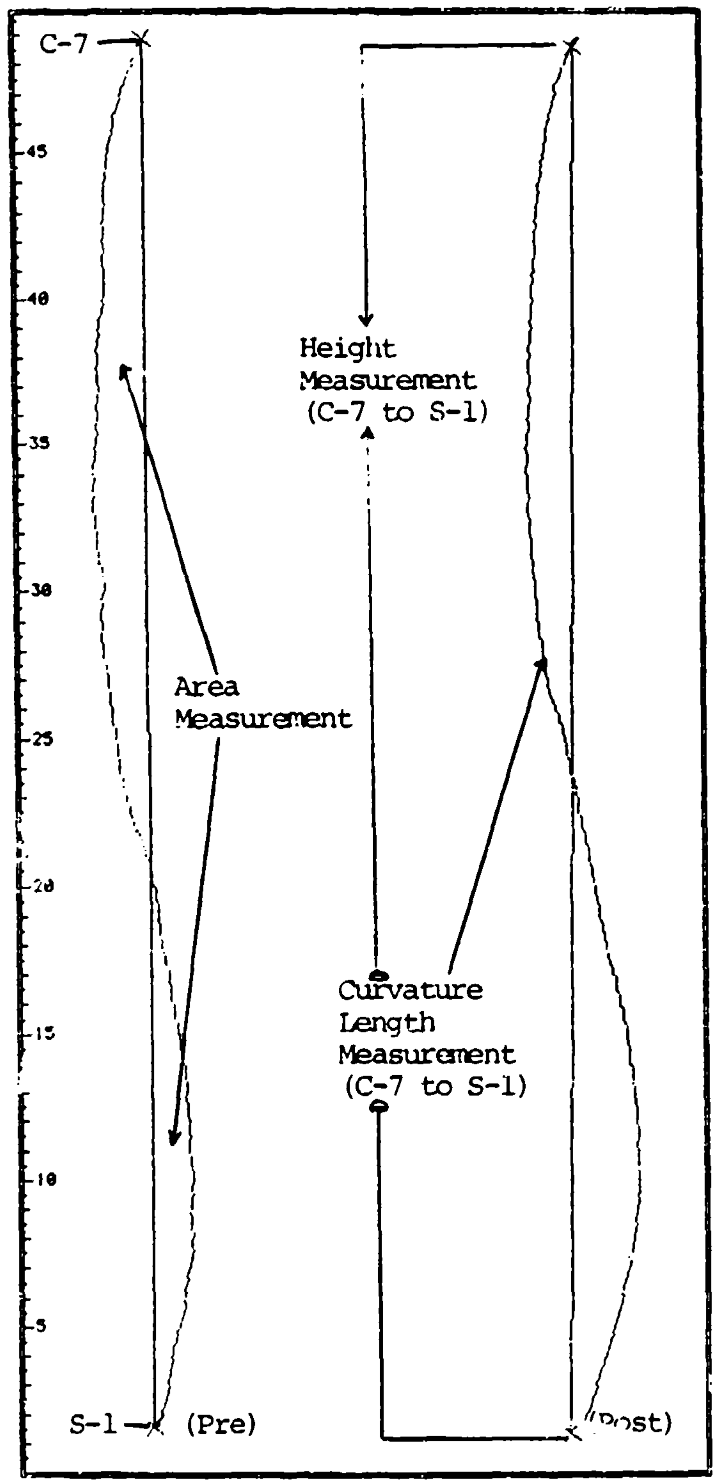


Figure 34. Spinal Creep Measurement Points.

TABLE 21

Spinal Creep Area Change. ANOVA and Duncan's Multiple Range Test

SOURCE OF VARIATION	DF	SUM OF SQUARES	F RATIO	LEVEL OF SIGNIFICANCE
Subject	11	2727.6075	1.35	0.2683
Seat	2	1572.2370	4.30	0.0280
Order	2	319.6154	0.87	0.4336

DUNCAN'S GROUPING*	MEAN**	N	SEAT TYPE
A	-4.570	12	CURRENT
A			
B A	3.514	12	MOD-REG
B			
B	11.643	12	MOD-CONF

* Means with the same letter are not significantly different at alpha = 0.05, df = 20, and mean square error = 183.379.

** Area difference between pre and post spinal contour measurements, in cm^2.

indicated that subjects tended to increase in their spinal area measurement for the MOD-CONF and MOD-REG, whereas the current aircrew seat tended to cause the area to decrease from pre- to post-test measurements.

Table 22 presents the analysis for the spinal creep length change. Again, as occurred in the spinal creep area analysis, the MOD-CONF and the current aircrew seat were significantly different from one another and the MOD-REG was statistically equivalent to both. Both the MOD-CONF and MOD-REG increased the subjects' curvature length, whereas the current aircrew seat decreased the length.

Anthropometric Measurement

A comparison of ten standards anthropometric measurements was performed during the vibration study to determine how closely the twelve vibration subjects emulated male rated officers in the United States Air Force (Kennedy, 1986). Figure 35 illustrates the anthropometric collection form used. Table 23 contains the data from the current study, including the means and minimum to maximum range values, as well as USAF rated officers' fifth percentile, mean and ninety-fifth percentile measurement values. This provided a realistic view of how well the subjects matched the population they

TABLE 22

Spinal Creep Length Change. ANOVA and Duncan's Multiple Range Test

SOURCE OF VARIATION	DF	SUM OF SQUARES	F RATIO	LEVEL OF SIGNIFICANCE
Subject	11	16.3914	2.32	0.0492
Seat	2	6.2446	4.86	0.0190
Order	2	4.5769	3.56	0.0475

DUNCAN'S GROUPING*		MEAN**	N	SEAT TYPE
	A	-0.2808	12	CURRENT
	A			
B	A	0.2125	12	MOD-REG
B				
B		0.7392	12	MOD-CONF

* Means with the same letter are not significantly different at alpha = 0.05, df = 20, and mean square error = 0.642408.

** Length difference between pre and post spinal contour measurements, in cm.

AIRCREW SEAT STUDY

NAME________________________________

DATE________________________________

AGE_________________________________

Anthropometric Data	in cm
1. Acromion Height, Sitting	1.________
2. Biacromial Breadth	2.________
3. Buttock-Knee Length	3.________
4. Elbow Rest Height	4.________
5. Elbow Grip Length	5.________
6. Hip Breadth, Sitting	6.________
7. Knee Height, Sitting	7.________
8. Stature	8.________
9. Weight (Mass) (lbs.)	9.________

Figure 35. Anthropometric Measurement Form.

TABLE 23

Anthropometric Measurements: Vibration Subjects vs. USAF Rated Officers (Kennedy,1986)

BODY MEASUREMENT*	VIBRATION STUDY N =12		USAF RATED OFFICERS N = 2420	
Acromion	MIN	53.10	5%tile	56.50
Height	MEAN	58.82	MEAN	61.05
Sitting	MAX	61.90	95%tile	65.90
Age	MIN	23.00	5%tile	22.60
(years)	MEAN	27.67	MEAN	30.03
	MAX	37.00	95%tile	42.80
Biacromial	MIN	36.00	5%tile	37.50
Breadth	MEAN	41.69	MEAN	40.73
	MAX	46.60	95%tile	43.50
Buttock	MIN	58.60	5%tile	56.10
Knee	MEAN	62.19	MEAN	60.40
Length	MAX	69.80	95%tile	65.00
Elbow	MIN	17.70	5%tile	19.60
Rest	MEAN	21.76	MEAN	23.98
Height	MAX	25.50	95%tile	28.60
Elbow	MIN	33.60	5%tile	31.70
Grip	MEAN	36.98	MEAN	35.20
Length	MAX	39.80	95%tile	37.90
Hip	MIN	33.00	5%tile	34.20
Breadth	MEAN	36.38	MEAN	37.79
Sitting	MAX	42.10	95%tile	41.80
Knee	MIN	51.70	5%tile	51.70
Height	MEAN	56.72	MEAN	55.76
Sitting	MAX	64.00	95%tile	59.90

* Measured in cm.

TABLE 23 (continued)

BODY MEASUREMENT*	VIBRATION STUDY		USAF RATED OFFICERS	
Stature	MIN	164.70	5%tile	167.20
	MEAN	179.13	MEAN	177.34
	MAX	188.50	95%tile	187.70
Weight	MIN	55.36	5%tile	63.61
(Mass)	MEAN	77.05	MEAN	78.20
(Kgs)	MAX	98.41	95%tile	95.60

* measured in cm.

were approximating so that their comments concerning design criteria would be valid for the pilot population.

From the anthropometric measurements taken, sixty percent of the current study minimum measurements were less than the comparable USAF fifth percentile individual. Seventy percent of the maximum measurement values were greater than the ninety-fifth percentile USAF rated officer. Additonally, when comparing the mean values from one population to the other, the largest difference, for any measurement, was only two centimeters. Essentially, this information indicated that, in a majority of the cases, the vibration subjects satisfied the fifth to ninety-fifth percentile design criteria and were very close to all of the mean measurement values. The individual anthropometric measurements for the vibration study can be found in Appendix H.

RESULTS OF EXPERIMENT NO. 2

Maximum Seat Pan Pressure

In the static pressure study, a fourth seat pan was added to the already existing seat pans in the dynamic vibration exposure study. This seat pan was essentially the same exact design as the current AMI aircrew seat

except that the regular polyurethane foam pad was replaced with an equivalent sized pad of Confor foam. The results of the maximum seat pan pressure testing is presented in Table 24. Seat pan pressure varied with seat type, and the Duncan's Groupings presented indicated that there were major differences among seat types. It is interesting to note that the current AMI aircrew seat had the highest (mean) maximum seat pan pressure (215.367 mm Hg.). This was significantly different from the next highest (mean) maximum pressure, which was 149.400 mm Hg, generated by the current seat with confor foam. Both the MOD-REG (101.567 mm Hg.) and MOD-CONF (92.933 mm Hg.) were statistically different than the previous two aircrew seats, however they were non-discriminable from each other. The raw data for the seat pressure study can be found in Appendix I.

Anthropometric Measurement

A comparison of ten standard anthropometric measurements was performed during the static pressure experiment to determine how closely the fifteen pressure subjects approximated male, rated officers in the United Air Force (Kennedy, 1986). Table 25 presents the anthropometric measurements from the pressure study in terms of means, minimum and maximum values. Also

TABLE 24

Maximum Seat Pan Pressure. ANOVA and Duncan's Multipie Range Test

SOURCE OF VARIATION	DF	SUM OF SQUARES	F RATIO	LEVEL OF SIGNIFICANCE
Subject	14	34680.3583	7.42	0.0001
Seat	3	141911.2833	141.65	0.0001

DUNCAN'S GROUPING*	MEAN**	N	SEAT TYPE
A	215.367	15	CURRENT
B	149.400	15	CURRENT W/CONF
C	101.567	15	MOD-REG
C			
C	92.933	12	MOD-CONF

* Means with the same letter are not significantly different at aipha = 0.05, df = 20.

** Measured in mm Hg.

TABLE 25

Anthropometric Measurements: Pressure Subjects vs. USAF Rated Officers (Kennedy,1986)

BODY MEASUREMENT*	PRESSURE STUDY N =12		USAF RATED OFFICERS N = 2420	
Acromion	MIN	57.50	5%tile	56.50
Height	MEAN	59.97	MEAN	61.05
Sitting	MAX	65.50	95%tile	65.90
Age	MIN	22.00	5%tile	22.60
(years)	MEAN	29.73	MEAN	30.03
	MAX	44.00	95%tile	42.80
Biacromial	MIN	36.90	5%tile	37.50
Breadth	MEAN	41.29	MEAN	40.73
	MAX	46.80	95%tile	43.50
Buttock	MIN	55.40	5%tile	56.10
Knee	MEAN	60.36	MEAN	60.40
Length	MAX	67.40	95%tile	65.00
Elbow	MIN	19.50	5%tile	19.60
Rest	MEAN	23.04	MEAN	23.98
Height	MAX	26.80	95%tile	28.60
Elbow	MIN	32.90	5%tile	31.70
Grip	MEAN	35.07	MEAN	35.20
Length	MAX	39.20	95%tile	37.90
Hip	MIN	33.20	5%tile	34.20
Breadth	MEAN	37.04	MEAN	37.79
Sitting	MAX	40.70	95%tile	41.80
Knee	MIN	49.50	5%tile	51.70
Height	MEAN	54.27	MEAN	55.76
Sitting	MAX	60.80	95%tile	59.90

* Measured in cm.

TABLE 25 (continued)

BODY MEASUREMENT*	PRESSURE STUDY		USAF RATED OFFICERS	
Stature	MIN	167.90	5%tile	167.20
	MEAN	177.43	MEAN	177.34
	MAX	193.80	95%tile	187.70
Weight	MIN	65.46	5%tile	63.61
(Mass)	MEAN	78.18	MEAN	78.20
(Kgs)	MAX	98.19	95%tile	95.60

* measured in cm.

provided is the mean, fifth and ninety-fifth percentile measurement values of rated male officers. In this manner, an appropriate comparison can be made to determine the extent which the current subjects approximate the flying population.

Of the ten anthropometric measurements made per individual, seventy percent of the current study measurements had at least one value above the ninety-fifth percentile USAF male rated officer and sixty percent had at least one measurement which was below the fifth percentile. Overall, the mean anthropometric measurement values from the static pressure study and the USAF flying personnel only differed by two percent or less. Thus, the population used in the pressure study very closely approximated the actual male rated officer population for the ten measurements taken. The anthropometric measurements for the subjects in the seat pressure study can be found in Appendix H.

CHAPTER V

CONCLUSIONS AND RECOMMENDATIONS

GENERAL CONCLUSIONS

All of the subjective measures (Aircrew General Comfort Rating, Aircrew Body Part Discomfort Survey, Aircrew Seat Feature Checklist and Post Test) were found to be useful tools for the assessment of aircrew seat design and comfort. Statistically significant differences between seat types were identified by these measures throughout the entire research endeavor. These subjective measures were directly compared against the objective measures of spine creep and maximum seat pan pressure and were found to consistently support the results and findings of these measures. In terms of aircrew comfort, the MOD-CONF and MOD-REG aircrew seats were both statistically different and substantially better, in all cases, than the current aircrew seat, thus supporting the design criteria.

Although there were aspects of the performance measures which provided significant (or very close to significant) differences, on the whole, performance was typically unaffected by seat type. This provided a direct reflection of man's ability to compensate and

adapt to his environment, for short durations of time, just as he has had to do during the evolution of flight.

SPECIFIC CONCLUSIONS

Human Performance

The results of this research indicated that, during the second period, there were statistically significant differences between the three aircrew seat types when performing the Pattern Comparison Task. This is consistent with the research performed by Mackie et al. (1974) in which they noted performance decrements during tasks which required pattern comparison and recognition. Performance was noticeably better while seated in the MOD-CONF and MOD-REG aircrew seats than when seated in the current AMI seat.

Although none of the other performance tasks were statistically responsive to seat type, several were very close in the third period. This finding is not altogether surprising since Guignard and King (1972) had reported that compensatory adaptation may be seen, in which man learns how to manage his tasks in spite of the vibration environment. Thus, it would seem that, for at least the one and one-half hour test, individuals can accommodate as long as the task is not overly demanding

physically or mentally. It is suspected that if this study had been performed so as to simulate a typical five hour C-130 flight, the degradation which would have been created by discomfort and fatigue would have shown a greater diversification of statistically significant differences between the three aircrew seats tested.

Aircrew General Comfort

The Aircrew General Comfort Rating questionnaire, used during this research, was easily used by the subjects and provided a data base for statistical analyses. The Aircrew General Comfort Rating results, for each of the three time periods, showed that there were statistically significant differences between the current and the MOD-CONF and MOD-REG aircrew seats. During the measurement periods, test participants reported the greatest level of comfort while performing tasks in the MOD-CONF and MOD-REG aircrew seats. The least comfortable aircrew seat, by a large margin, was the current AMI seat. After an hour and a half of vibration exposure, combined with performance tasks, the MOD-CONF and MOD-REG aircrew seats were transitioning into the "quite comfortable" rating area, whereas the current seat was transitioning into the "uncomfortable" rating realm.

The results of the Aircrew General Comfort Rating directly support the conclusion that both the MOD-CONF and MOD-REG aircrew seats were superior to the current AMI aircrew seat from a comfort standpoint.

Body Part Discomfort

The Aircrew Body Part Discomfort Survey, used during this research effort, proved to be understandable and easily used by the test subjects. Statistical analyses of the data collected were performed to determine the extent of body part discomfort caused by each of the three aircrew seats. Both buttock and thigh discomfort showed significant differences in the three aircrew seat types.

In all three time periods, the results of the analyses showed that the buttock discomfort associated with the current aircrew seat was greater than either the MOD-CONF or MOD-REG seats. In the final time period, subjects had rated the current seat as approaching "moderate pain/discomfort", whereas neither the MOD-REG nor the MOD-CONF had been identified as causing even "just noticable pain/discomfort" to the buttocks. During the second time period, the three aircrew seats were significantly different in terms of pain/discomfort generated in the subjects' thighs. In this instance, the

current aircrew seat was again rated as causing more pain/discomfort than the other two seats.

The results of the body part discomfort analyses directly supports the conclusion that that both the MOD-CONF and MOD-REG aircrew seats were superior to the current AMI seat from a body part discomfort standpoint. The results from these analyses are in direct concurrence with the results and conclusions generated by the aircrew general comfort analyses.

Aircrew Seat Feature Checklist

The Aircrew Seat Feature Checklist employed during this study was found to be successful in identifying design problem areas and also in gathering useful data to facilitate statistical analyses. There were eight areas where statistically significant differences were found between seat types. In all eight instances, the MOD-CONF and MOD-REG aircrew seats were statistically equivalent, whereas the current AMI aircrew seat was always significantly different than the other two aircrew seats. The eight seat features which were statistically different, based upon seat type were: seat pan width, seat pan shape, seat pan padding, backrest shape, backrest curvature, lumbar support, backrest padding and overall opinion of aircrew seat. The MOD-CONF seat was

rated superior for seat pan width, seat pan shape, seat pan padding, backrest shape, curvature of backrest and lumbar support. The MOD-REG was rated superior for backrest padding and just barely higher on overall opinion than the MOD-CONF seat.

The favorable aircrew seat feature ratings which the MOD-CONF and MOD-REG aircrew seats received were another way of verifying the presence of a better design. Just as the Aircrew General Comfort Ratings related to the Body Part Discomfort Survey results, they both also reinforced the findings of the Aircrew Seat Feature Checklist.

The current AMI seat was classified as having a seat pan which was too narrow, did not conform to the buttocks very well and additionally needed much more padding. The backrest was identified as fitting neither the shape nor the curvature of the subjects' backs and was in dire need of lumbar support. These findings relate directly to the high levels of buttock, thigh and lower back pain/discomfort noted by the participants. It also helps explain the less than satisfactory general comfort ratings which the current seat received.

Post Test

The Post Test questionnaire used during this experiment provided rank information which helped to identify which of the three aircrew seats subjects preferred most. The analysis performed identified the MOD-CONF as the most favored aircrew seat. The MOD-REG was a close second, with the current AMI aircrew seat being ranked last by all subjects. This, again, added credibility to the results of the previous endeavors.

Spinal Creep

Prior to, and immediately following each vibration exposure, each subject was measured on the spinal contour measurement device. The data gathered from this was analyzed to determine the differences between pre- and post-test measurements. The measurements were: the length of the spine curvature segment from C-7 to S-1, the straight-line height of the spinal column segment from C-7 to S-1 and the area enclosed above and below the straight line from C-7 to S-1, bounded by the curvature.

The analyses preformed revealed that there were statistically significant differences between seat types in both the change of area and change of curvature length measurements. Both the MOD-CONF and MOD-REG seats caused

an overall increase in the subjects' spine area and spine curvature length. This equated to an increase in lumbar lordosis (curve of the lumbar spine), which placed them in a position which closer approximated that of balanced muscle relaxation (optimal being 135 degree trunk-thigh angle). The current aircrew seat, on the other hand, caused subjects to experience an average decrease in lumbar lordosis and curvature length. This flattening of the lumbar spine tends to stretch the overlying nerve root, and increases nerve root irritation and gluteal (buttock) and lower extremity pain (Keegan, 1953).

The spinal measurement results were found to be in-line with previously reported subjective pain/discomfort ratings. Additionally, the problems identified in the Aircrew Seat Feature Checklist were the exact areas which could affect lumbar spine curvature, therefore directly affecting lower back and buttocks discomfort.

Maximum Seat Pan Pressure

By utilizing a contoured seat pan for both the MOD-CONF and MOD-REG aircrew seats, the buttock-thigh contact surface area was enhanced, thus allowing the seat pan pressure to be distributed more evenly. The results of the maximum pressure testing identified statistically significant differences between the four seat pan types

tested. The current seat pan had significantly higher (mean) maximum seat pan pressures than any of the other seat pans. The current aircrew seat with Confor foam (CURRENT-CONF) provided the next highest (mean) maximum pressures. Statistically, it was lower than the current aircrew seat with regular foam, however it was still significantly higher than either of the two modified versions. The MOD-CONF and MOD-REG both had the lowest (mean) maximum seat pan pressures recorded.

The seat pan pressures measured on the MOD-CONF and MOD-REG aircrew seat provided yet another objective means of verifying the subjective results, which again are indicative of aircrew seats which are superior to the current aircrew seat.

RECOMMENDATIONS FOR FUTURE RESEARCH

Recommendations for future research are provided to try to eliminate any short-comings or limitations identified during the current research effort and also to try to identify appropriate areas of expansion where this research could logically progress.

Performance Measures

The use of human performance measures, specifically the Memory Search Task, Pattern Comparison Task, Combined Memory Search - Tracking Task and Critical Tracking Task, were limitedly useful in highlighting differences in human performance while seated in a vibration environment. To gain a better grasp of the usefulness of these tasks in measuring human performance in a vibration environment, it is suggested that the duration of time which the subjects experience the treatments be extended. This will allow the participants to experience the necessary performance and fatigue degradati· · normally associated with the flying environment.

If this is not a feasible option, then the vibration environment could be suitably changed to create a more demanding and fatiguing environment.

A final option would be to utilize more physically and mentally demanding tasks which would be more fatiguing than those currently employed, while still allowing the subjects to provide adequate feedback concerning the comfort and design of the aircrew seat.

Flight Testing

The redesign or modification of the current C-130A aircrew seat (and potentially other aircraft aircrew seats) was a solution which will allow the Air Force and other flying organizations to increase performance and comfort while minimizing pilot fatigue on long duration flights. The systematic approach outlined in the methodology section is a proven format which will be useful to future experimentation on any aircrew seat. The current study was specifically designed such that if flight testing of the aircrew seats became a viable option in the future, the experimental design and methodology could be directly applied with relatively minor modification.

Initially, the entire WAD system and the aircrew seats could be palletized and loaded in the front of the C-130 cargo bay. The experimental design and layout would remain essentially the same except the subjects would experience more test runs due to the longer duration of the test. The WAD system would need to be modified to run off of the aircraft's 28 volt system and the racks for the control stick box and to hold the color monitor would have to be removed from the SIXMODE at Wright-Patterson AFB, OH and bolted onto a C-130 pallet.

Data collected inflight could then be compared to that gathered during the vibration experiment.

Following validation by this means, flight test involving current C-130 pilots and co-pilots could be accomplished. This testing would involve gathering inflight subjective data when one pilot was seated in the current C-130 AMI aircrew seat and the other was seated in a modified version. Starting just prior to take-off and at one hour increments thereafter, the pilot and co-pilot would be asked to fill out the Aircrew Body Part Discomfort Survey and the Aircrew General Comfort Rating questionnaires. Data collection would continue for as long as the mission continued. At the termination of the mission, the pilots would be asked to fill out the Aircrew Seat Feature Checklist. The subjects would be randomly selected from flights which were scheduled to fly on the identified testing days. The experimental design would be a Latin Square design. An analysis of variance (ANOVA) would be performed to determine if specific aircrew seats differed from the others. This data could be compared to that collected via the simulated flight environment on the SIXMODE Vibration Table.

In this manner, the C-130A as well as other airlift aircraft aircrew seats could be validated in-flight to

determine the improvements asscciated with a new seat design. Additionally, it would provide future designers with valid design criteria and testing techniques to help improve one on the most important human interfaces in the ent. aircraft cockpit, the aircrew seat.

Fighter Aircraft Seats

Besides the obvious usefulness of this aircrew seat design for the transport aircraft community, the broader scope of this idea could well encompass the ejection seat arena. Testing could be performed to determine if the contoured seat design would provide enough support, to an individual ejecting from an aircraft, so that the chances of injury were minimized. With G-forces in excess of 20 g's, the seat not only must be extremely durable, but additionally must be aerodynamic enough to stabilize the individual so that man-seat separation can be accomplished without serious tumbling or spinning. If testing could be performed to ensure the safety of the aircrew seat in the high G environment, the use of the modified aircrew seat could potentially be as advantageous in the fighter aircraft community as in the transport.

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APPENDIX A

CONSENT FORM

Consent Form
Subjective Effects of Aircrew Seat Redesign Study

I, ______________________, am participating because I want to. The decision to participate in this research study is completely voluntary on my part. No one has coerced or intimidated me into participating in this program.

________________________ has adequately answered any and all questions I have asked about this study, my participation, and the procedures involved, which are set forth in the addendum to this Agreement which I have initialed. I understand that the Principal Investigator or his designee will be available to answer any questions concerning procedures throughout this study. I understand that if significant new findings develop during the course of this research which may related to my decision to continue participation, I will be informed. I further understand that I may withdraw this consent at any time and discontinue further participation in this study without prejudice to my entitlements. I also understand that the Medical Consultant for this study may terminate my participation in this study if he/she feels this to be in my best interest. I may be required to undergo certain further examinations, if in the opinion of the Medical Consultant, such examinations are necessary for my health or well being.

I understand that in the event of physical injury resulting from the research procedures described to me that only acute, immediate, or essential medical treatment is available. I understand that my entitlement to medical care or compensation in the event of injury are governed by federal laws and regulations, and that if I desire further information I may contact the Principal Investigator. I have not been requested to waive or release Texas A&M University, its agents or sponsors from liability for the negligence of its agents or employees.

I understand that for participation in this project I shall be entitled to payment as specified in the DoD Pay and Entitlement Manual or in current contracts.

I understand that my participation in this study may be photographed, filmed or audio/videotaped. I consent to the use of these media for training purposes and understand that any release of records of my participation in this study may only be disclosed according to federal law, including the Federal Privacy Act, 5 U.S.C. 522a, and its implementing regulations. This means personal information will not be released to an unauthorized source without my permission.

I FULLY UNDERSTAND THAT I AM MAKING A DECISION WHETHER OR NOT TO PARTICIPATE. MY SIGNATURE INDICATES THAT I HAVE DECIDED TO PARTICIPATE HAVING READ THE INFORMATION PROVIDED ABOVE.

______________________________ ______________________
VOLUNTEER SIGNATURE AND SSAN DATE

______________________________ ______________________
WITNESS SIGNATURE DATE

APPENDIX B

GENERAL DESCRIPTION OF SIXMODE FACILITY (MUHIC, 1980)

SIXMODE MOTION SIMULATOR

The SIXMODE motion simulator and its associated hydraulic power supply is a large complex man-rated electrohydraulic machine capable of sinusoidal, quasi-random, or random motion in six-degrees of freedom. There are six large servo controlled hydraulic actuators which drive the system. Motion can be controlled in all combinations of x, y, z, roll, pitch, or yaw.

The SIXMODE control system includes a complement of sine and random noise signal generators and monitoring equipment, including a seven-channel sine generator for quasi-random (sum of sines) programs. Experimental data can be acquired on line using a DEC (Digital Equipment Corporation) PDP-11/34 Data Acquisition and Processing System also data can be stored on high density disks for later analysis. Forcing functions for the SIXMODE are controlled by a multiaxis programmer. This device provides for selecting individual operating modes or combinations of modes. Each selected mode has its own individual forcing function input, as well as variable gain control.

An automatic shutdown system (ASDS) monitors both linear and angular accelerations as well as all six actuator positions. If any of the preset parameters are exceeded the ASDS causes the hydraulic and electronic failsafe systems to be engaged and also commands all electrical driving signals to gradually decrease in magnitude through a "ramp down" function. The hydraulic failsafe and numerous interlocks are also activated if an improper start-up sequence is attempted.

The SIXMODE Vibration Facility had been safety certified (mandated) by the AAMRL Safety Office. This procedure included an inspection of operation, safety, and emergency procedures by the AAMRL Technical Safety Committee. A copy of the safety permit was posted in the SIXMODE control room. A detailed description of standard operating procedures had been developed for the SIXMODE system and was documented in the SIXMODE safety file. A copy of the operating procedure was also kept at the test facility operator's console for reference. Safety certification was accomplished on a yearly basis or when significant changes occurred in SIXMODE equipment or operation. A particular test was conducted only if the SIXMODE had a current safety certification and mandating.

Detailed checklists for the operation of the SIXMODE and its support equipment have been developed. The

facility operator was required to document use of these checklists each time the SIXMODE was operated. Additional checklists designed for each experiment were provided for the facility operator and the test administrator. These checklists specified the particular vibration spectrum that would be administered to each subject and included provisions for recording experimental data. The standard instrumentation employed for all SIXMODE runs was used. The instrumentation consisted of accelerometers for each of the relevant degrees-of-freedom, strip chart recording of each of these signals, and a true RMS meter to indicate table acceleration in the primary axis of motion. The outputs of the accelerometers were recorded on the strip chart and magnetic tape, and displayed on a true RMS meter.

Building 824 contained medical treatment equipment such as an AMBU Resuscitator, EKG/defibrillator, laryngoscopy and tracheostomy trays, and appropriate drugs and intravenous solutions. The building was supplied with litters, firefighting equipment, and a sprinkler system. An ambulance hotline was available in the SIXMODE area. Personnel at Occupational Medicine Services (Bldg. 40) were alerted via the hotline prior to the beginning of vibration runs involving human subjects.

The hydraulic energy to power the SIXMODE is produced

by a large hydraulic power supply located in an adjoining area. This power supply is capable of a delivery rate of 1000 GPM at 3000 PSI. The basic system includes 6 axial type hydraulic pumps each driven by a 350 HP electric motor operating at 1800 RPM.

Each of the six hydraulic actuators associated with the SIXMODE has two 60 GPM servovalves operating in a parallel configuration and six corresponding electronic servo loops which are individually compensated and controlled. The electronic servo loops utilize a hybrid analog computer which affords maximum versatility in changing compensation and actuator responses for specific projects. This hybrid analog computer also allows for pushbutton selection and display of voltages within all six servo control loops. All servovalve power amplifiers and associated power supplies are conservatively rated for maximum subject safety.

The SIXMODE failsafe and interlock systems are equipped with unique failsafe hydraulic manifolds and control solenoids which shunt across both hydraulic control pressure ports for each actuator, in the event of a malfunction. The key to this fail-safe system is a movable hydraulic spool held in place by the hydraulic system pressure. Removal of solenoid power or hydraulic pressure causes each hydraulic actuator to lose all

driving force and, in essence, the actuators become very "mushy" shock absorbers. Failsafe activation may be accomplished either manually or automatically.

The current man-rating license for the SIXMODE limits operation, with human subjects, far below the maximum capabilities of the system. This policy is concurrent with the practice of setting the ASDS operational limits to only what is needed for an approved human operational protocol. The device can, however, be operated at higher levels with the approval of the Air Force Human Use Committee. Single actuators can also be isolated for high force, long stroke applications, needed in some high force, long stroke applications, needed in some non-human or material properties tests.

Experimental Risks

Vibration exposures during this experiment did not exceed the exposure limits specified in ISO Standard 2631, AFSC Design Note 3E1, and MIL-STD-1472C, for the appropriate vibration directions, frequencies, and durations. The limits specified in these standards had been set at approximately one-half the limit of voluntary tolerance. Vibrations in the frequency range that were used in the Aircrew Seat Redesign Study (2.0 to 20 Hz, not to exceed .5 G_z) may be characterized as similar to

what one might experience on a walking horse at low frequencies, or driving a car over a "washboard" road, at the high frequencies (Schoenberger, 1980).

Physical symptoms which have been experienced under very severe vibration conditions (at the limits of voluntary toleration for very short exposure durations) include: headache; interference with vision and speech; interference with respiration; pain in the chest, abdomen, back, testicles, and buttocks; and feelings of anxiety and general discomfort (Temple, Clarke, Brinkley and Mandal, 1964; Mandel and Lowry, 1962; Magid, Coerrman and Ziegenruecker, 1960). Since the vibration exposure limits for the proposed tests were nominally one-half the limits of voluntary tolerance, these potential adverse physical effects were considered to be well within human tolerance and similar to those associated with mild exercise. During several hundred previous exposures in tests conducted at AAMRL at equal or greater levels, no physical or medical problems were experienced by any of the subjects, and the attendant discomfort and risks were considered minimal (Schoenberger, 1980, 1976, 1970; Temple et al., 1964; Mandel and Lowry, 1962; Magid et al., 1960). The overall risk of the vibration exposures under this experiment was therefore believed to be acceptably small and outweighed by the benefits to be

derived from the proposed research. Medical problems during testing were to be immediately reported to the medical investigator and appropriate medical assistance and/or consultation would have been provided.

General Specifications for Human Protocol

Frequency Range	-	DC - 30 Hz.
Motion	-	six degrees of freedom, x, y, z, roll, pitch, and yaw.
Displacement	-	system limits are approved for 6 inches double amplitude. (D.A.) individual actuators have 10 inches D.A. usable range.
Force	-	Each actuator is capable of 20,000 force lbs. maximum @ 2,000 PSI.
Acceleration	-	1.5 g-peak linear and 15 rad/sec^2 peak angular for human tests. Significantly higher acceleration levels are achievable for non-human tests.
Test Platform	-	one piece aluminum table 59" x 59" with 5/8 x 18 thread per inch on 5" centers, coupled to six actuators by zero backlash hydrostatic and elastomeric couplers.
Payload	-	2,000 lbs. maximum.
Hydraulic Power Supply	-	1,000 GPM @ 3,000 PSI.

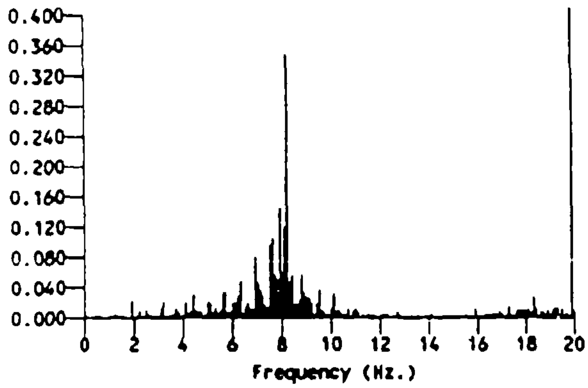
Testing limits are set at levels needed to complete existing human test protocols only. Higher limits are achievable for non-human tests.

APPENDIX C

EXAMPLE OF PSD

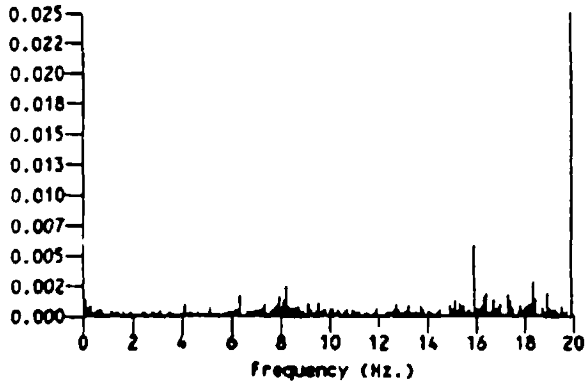
Roll (Rad/Sec/Sec)

DC component	= 0.002 volts
RMS theoretical	= 0.000 Rad/Sec/Sec
RMS meter	= 0.000 Rad/Sec/Sec
Total RMS	= 0.633 Rad/Sec/Sec
Total RMS less DC	= 0.633 Rad/Sec/Sec
Bandpass RMS	= 0.630 Rad/Sec/Sec
Bandpass RMS less DC	= 0.630 Rad/Sec/Sec



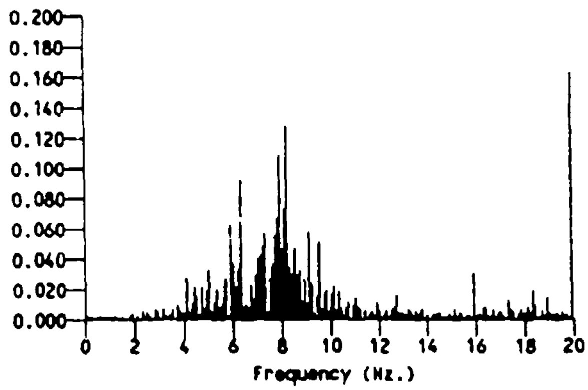
X (G)

DC component	= 0.001 volts
RMS theoretical	= 0.000 G
RMS meter	= 0.000 G
Total RMS	= 0.028 G
Total RMS less DC	= 0.028 G
Bandpass RMS	= 0.027 G
Bandpass RMS less DC	= 0.027 G



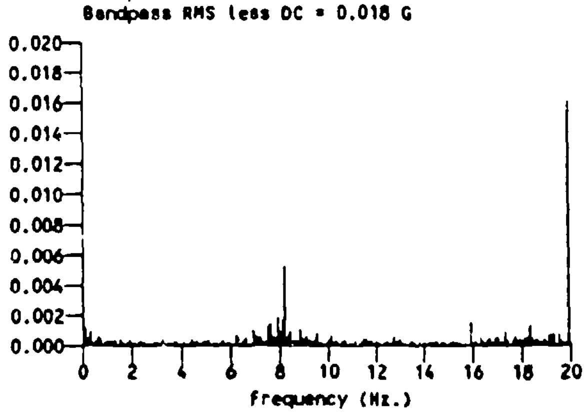
Pitch (Rad/Sec/Sec)

DC component	= 0.007 volts
RMS theoretical	= 0.000 Rad/Sec/Sec
RMS meter	= 0.000 Rad/Sec/Sec
Total RMS	= 0.356 Rad/Sec/Sec
Total RMS less DC	= 0.356 Rad/Sec/Sec
Bandpass RMS	= 0.354 Rad/Sec/Sec
Bandpass RMS less DC	= 0.354 Rad/Sec/Sec



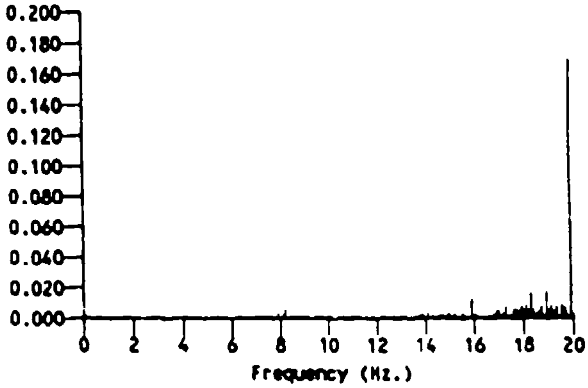
Y (G)

DC component	= 0.051 volts
RMS theoretical	= 0.000 G
RMS meter	= 0.000 G
Total RMS	= 0.055 G
Total RMS less DC	= 0.019 G
Bandpass RMS	= 0.055 G
Bandpass RMS less DC	= 0.018 G



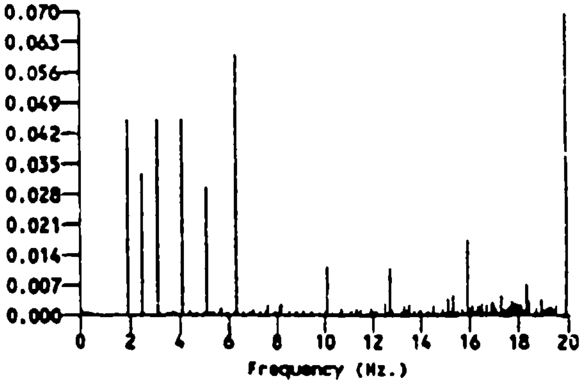
Yaw (Rad/Sec/Sec)

DC component	=	0.010 volts
RMS theoretical	=	0.000 Rad/Sec/Sec
RMS meter	=	0.000 Rad/Sec/Sec
Total RMS	=	0.179 Rad/Sec/Sec
Total RMS less DC	=	0.179 Rad/Sec/Sec
Bandpass RMS	=	0.177 Rad/Sec/Sec
Bandpass RMS less DC	=	0.176 Rad/Sec/Sec



Z (G)

DC component	=	0.006 volts
RMS theoretical	=	0.132 G
RMS meter	=	0.132 G
Total RMS	=	0.133 G
Total RMS less DC	=	0.133 G
Bandpass RMS	=	0.133 G
Bandpass RMS less DC	=	0.133 G



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